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SUMMARY OF RESEARCH 1996

Department of Aeronautics and Astronautics

Daniel J. Collins
Chair

Oscar Biblarz
Associate Chair for Research

Prepared for: Naval Postgraduate School
Monterey, CA 93943-5000

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral M.J. Evans
Superintendent

R. Elster
Provost

This report was prepared for the Naval Postgraduate School, Monterey, CA.

Reviewed by:

Danielle A. Kuska
Programs Supervisor
Research Office

Released by:

David W. Netzer
Associate Provost and Dean of Research

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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Aeronautics and Astronautics. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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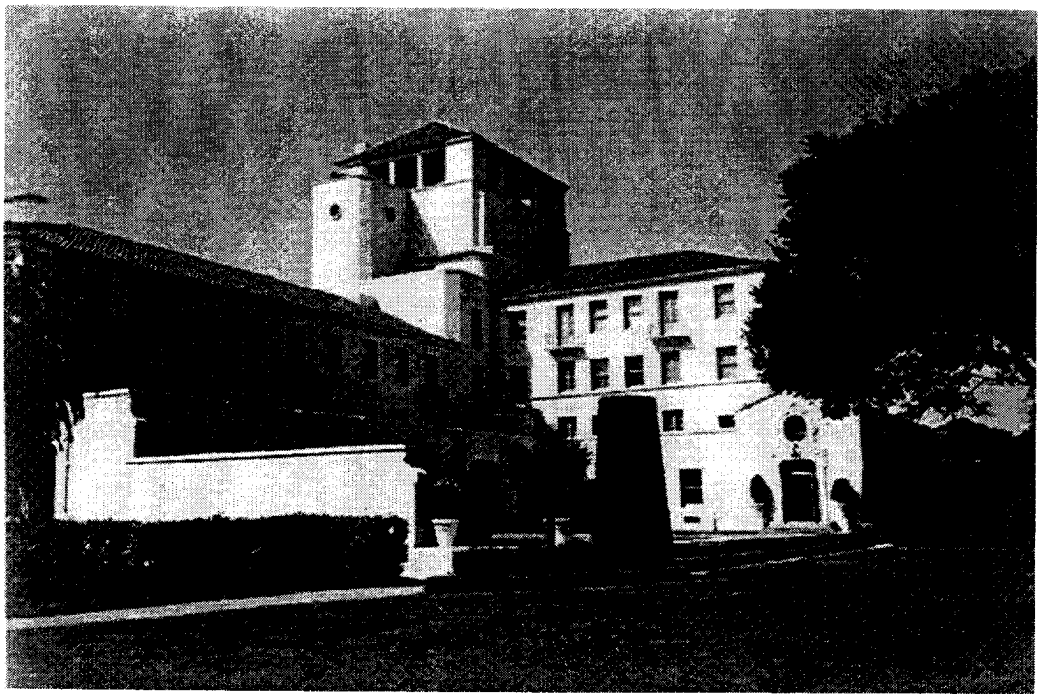
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

DANIEL J. COLLINS
CHAIR

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of US and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.



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Preface

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.
- Keep faculty on the leading edge of advances in defense-related science, technology, management and policy to ensure that the latest information is incorporated into NPS courses and curricula.
- Apply faculty and student knowledge to enhance DoN/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

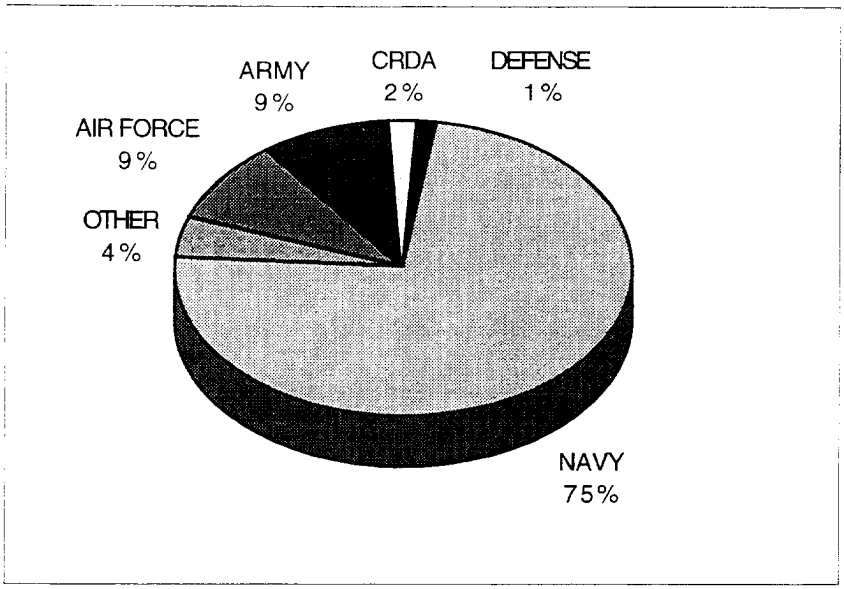
New technologies and policy changes will of course occur, necessitating changes in educational programs and stronger ties between the fleet and the support establishment. NPS must remain poised to face this challenge and to utilize emerging technologies and new policies within its curricula programs. Faculty, therefore, must stay abreast of these developments through a dynamic research program that helps fulfill the School's goals of excellence, uniqueness, and relevance.

The overall research program at NPS has three funded components. The Direct Funded Research and Institute for Joint Warfare Analysis Programs are institutionally funded within the School's operating budget. The Direct Funded Research Program is administered by the Associate Provost and Dean of Research. The Institute for Joint Warfare Analysis Program is administered by the Director of IJWA.

- The Direct Funded Research (DFR) Program provides funding to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.
- The Institute for Joint Warfare Analysis Research Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of faculty research.
- The Reimbursable Research (RR) Program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The three research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

In 1996, the level of the research effort at the Naval Postgraduate School was 141 faculty workyears and exceeded 29 million dollars. Eighty percent of the research was funded by reimbursable sponsors and 20 percent was funded by the Naval Postgraduate School. Sixty-five percent of the work was performed for the Navy and the remainder was sponsored by other agencies, both DoD and non-DoD. A profile of the reimbursable program of the Department of Aeronautics and Astronautics is provided in Figure 1:



Size of Program: $1,540K

Figure 1. Department of Aeronautics and Astronautics - Sponsor Profile

Research at NPS is carried out by faculty in the School's eleven Academic Departments, four Interdisciplinary Groups and the School of Aviation Safety. In the pages that follow, research summaries are provided for projects undertaken by faculty in the Department of Aeronautics and Astronautics during 1996. An overview and faculty listing are provided as an introduction. A list of publications is also included, if applicable. Abstracts for thesis advised by department faculty in 1996 complete this research summary.

Questions about particular projects may be directed to the Faculty Principal Investigator listed, the Department/ Group Chair, or the Department Associate Chair for Research. Questions may also be directed to the Research Office. General questions about the NPS Research Program should be directed to the Research Office at (408) 656-2098 (voice) or research@nps.navy.mil (e-mail).

August 1997

FACULTY LISTING

Collins, Daniel J.
Professor and Chair
AA/Co
408-656-2311 (phone)
408-656-2313 (fax)
collins@aa.nps.navy.mil

Biblarz, Oscar
Professor and Associate Chair for Research
AA/Bi
656-3096
obiblarz@aa.nps.navy.mil

Agrawal, Brij N.
Professor
AA/Ag
656-3338
agrawal@aa.nps.navy.mil

Ball, Robert E.
Distinguished Professor
AA/Bp
656-2885
ball@aa.nps.navy.mil

Chandrasekhara, Muguru
Professor
AA/Ch
415 604-4269
chandra@aa.nps.navy.mil

Duren, Russell W.
Associate Professor
AA/Dr
656-5039
duren@aa.nps.navy.mil

Sheshagiri K. Hebbar
Visiting Associate Professor
AA/Hb
656-1103
hebbar@aa.nps.navy.mil

Hobson, Garth V.
Associate Professor
AA/Hg
656-2888
garth@aa.nps.navy.mil

Howard, Richard M
Associate Professor
AA/Ho
656-2870
howard@aa.nps.navy.mil

Kaminer, Isaac I.
Assistant Professor
AA/Ka
656-5040
kaminer@aa.nps.navy.mil

King, Robert
Lecturer
AA/Ki
656-2944
rlking@aa.nps.navy.mil

Lindsey, Gerald H.
Professor
AA/Li
(408) 656-2808
lindsey@aa.nps.navy.mil

Netzer, David W.
Distinguished Professor
AA/Nt
656-3241
netzer@aa.nps.navy.mil

Newberry, Conrad
Professor
AA/Ne
656-2892
newberry@aa.nps.navy.mil

Platzer, Max F.
Distinguished Professor
AA/Pl
656-2058
platzer@aa.nps.navy.mil

Ross, I. Michael
Assistant Professor
AA/Ro
656-2074
ross@aa.nps.navy.mil

Scrivener, Sandra
Assistant Professor
AA/Ss
656-2936
sandi@aa.nps.navy.mil

Shreeve, Raymond P.
Professor
AA/Sf
656-2593
shreeve@aa.nps.navy.mil

Song, Gangbing
Assistant Research Professor
AA/Sb
656-2716
gsong@aa.nps.navy.mil

Tuncer, Ismail H.
Research Assistant Professor
AA/Tu
656-2854
tuncer@nps.navy.mil

Wood, E. Robert
Professor
AA/Wd
656-2897
rwood@aa.nps.navy.mil

Wu, Edward
Professor
AA/Wu
656-3459

DEPARTMENT SUMMARY

Research in the Department of Aeronautics and Astronautics is focused on topics of critical importance to military users. Typically, research activity resides in the Department's five technical committees, namely, Aerodynamics, Structures, Propulsion, Flight Mechanics and Controls, and System Design. Both aircraft and spacecraft are involved. Present Departmental endeavors are described below.

Aerodynamics

HIGH-ANGLE-OF-ATTACK MISSILE AERODYNAMICS: In support of the Naval Air Warfare Center, Weapons Division, Professors Platzer and Tuncer are developing solutions for the flow over missile configurations in steady and unsteady subsonic high angle of attack flight using Navier-Stokes and panel code modelling.

FLAPPING WING PROPULSION: In support of the Naval Research Laboratory, Professors Platzer and Tuncer are performing experimental and computational studies to explore flapping wing propulsion for micro-air vehicles.

NASA/USRA ADVANCED DESIGN PROGRAM: The primary focus of the NASA/USRA Advanced Design Program for aeronautical systems under Professor Newberry is the innovative design of deck-launched waverider configured aircraft. However, conventional aircraft, helicopter and missile system design were also completed. Research efforts involving interplanetary waverider-configured spacecraft using aero-gravity-assist and the LoFlyte (Mach = 5) configuration supported design class products.

TOPICS RELATED TO ROTORCRAFT AND VERTICAL FLIGHT: The rotary wing program led by Professor Wood has five areas. These are: (1) Sponsored research support of the Army's No. 1 Program, the RAH-66 Comanche helicopter. The prototype helicopter is now undergoing engineering flight development at Sikorsky's Test Center in West Palm Beach, FL; (2) Research in ground and air resonance of soft-inplane hingeless rotor systems to eliminate the instability without requiring heavy and costly blade dampers; (3) Technical support of McDonnell Douglas and SatCon Technology for application of Higher Harmonic Control for improved rotor performance; (4) Advanced engineering upgrades for rotorcraft in Special Operations Warfare; and (5) NOTAR=AE research using a 1/4 scale remotely piloted helicopter, the NPS Hummingbird I. In addition, NPS received two full scale OH-6A flightworthy helicopters from the Army National Guard in October 1995. One of the helicopters will be removed from flying status and serve as a baseline model for helicopter structural dynamics research. In this area, Professors Wood (Department of Aeronautics and Astronautics), Gordis (Department of Mechanical Engineering), and Danielson (Department of Mathematics) are being funded by the Army RAH-66 Comanche Office to provide a backup NASTRAN dynamic model of the Comanche to be used for exploring potential vibration problem areas.

ENHANCED HELICOPTER MANEUVERABILITY: Professors Chandrasekhara, Platzer and Tuncer are performing experimental and computational studies on the dynamic stall characteristics of helicopter blades. Experiments are being carried out to develop practical adaptive-geometry techniques for controlling flow separation. Also, Navier-Stokes methods are being developed to predict the formation of separation bubbles on the onset of dynamic stall. These studies are partially supported by the Army Research Office.

Structures

P-3 ORION LIFE EXTENSION PROGRAM: A life extension program is underway under Professor Wu. The strategy is to develop fatigue data for the aluminum alloy used in P-3 structures. Data collection is underway by constant amplitude fatigue and spectrum fatigue will make up the second phase of testing. Results of these testing phases will be compared such that a methodology for spectrum life prediction will be available. Verifications will be performed on new samples subjected to a load history entirely in the laboratory. This will allow a lead time to forewarn any refurbishment in the fleet.

Propulsion

ADVANCED AIRCRAFT ENGINE AND MISSILE PROPULSION STUDIES: Currently in its second phase, the goals of the third phase of the (tri-service, government/industry) Integrated High Performance Turbine Engine Technology (IHPTET) Program can only be reached by achieving very significant performance and weight advances in each of the engine components. Advancing fan and compressor and turbine aerodynamics (to allow higher-blade loading) is the focus of the work of Professors Shreeve and Hobson at the Turbopropulsion Laboratory. The general approach is to use the laboratory's exceptional experimental facilities to validate CFD codes being developed for use in advanced design. The off-design and stalling behavior of controlled-diffusion compressor blading is being measured in a very large-scale subsonic cascade wind tunnel. The alleviation of shock boundary-interaction losses is being studied in a transonic blow-down wind tunnel model simulation of the flow through fan passages. A new stage designed by NASA using 3D CFD codes is being prepared for evaluation in the transonic compressor rig. Pressure sensitive paint has been developed as a diagnostic for the rotor flow. The details of flow in the tip region of high speed turbines is to be studied using, as a tool, the Space-Shuttle Main-Engine fuel-pump turbine and an annular cascade. Two- and three-dimensional traversing Laser-Doppler Velocimeter (LDV) systems have been developed for velocity field mapping. The development of successful diagnostic techniques to resolve small-scale, three-dimensional effects near to walls is necessary to achieve the goals of this and the IHPTET program.

Flight Mechanics and Controls

UNMANNED AIR VEHICLE (UAV) TECHNOLOGY: In support of the DoD's role in the development of UAVs, Professor Howard has developed a UAV flight research laboratory at NPS using several flight platforms for the development and testing of flight control technologies and to address relevant issues of aerodynamics and flight mechanics. The broad goal is to develop innovative technologies and flight-control techniques applicable to UAVs, including HAE (high altitude endurance), Tactical, and Vertical Takeoff and Landing (VTOL) configurations. The current focus, jointly with Professor Kaminer, is on the development of autonomous guidance, navigation and control of a conventional air vehicle. Flight testing of the avionics, airborne sensors, and datalinks is underway. Other projects include a scaled drop simulation of a NASA experiment, a study of future applications of the Global Hawk Tier 2+ UAV, and the development of a miniature onboard data-acquisition and sensor suite. Professors Howard, Kaminer and Netzer are also investigating a lethal UAV concept for the detection and destruction of ballistic missile launchers prior to launch.

INTEGRATED GUIDANCE AND CONTROL FOR AIR VEHICLES: The work by Professor Kaminer addresses the problem of integrated design of guidance and control systems for autonomous vehicles (AVs). In fact, we have developed a new methodology for integrated design of guidance and control for autonomous vehicles. The methodology proposed leads to an efficient procedure for the design of controllers for AVs to accurately track reference trajectories defined in an inertial reference frame. This methodology was applied to the design of a tracking controller for the Unmanned Air Vehicle Frog at the NPS UAV Lab.

DEVELOPMENT OF TAIL SIZING CRITERIA FOR A SUPERSONIC TRANSPORT: Professor Kaminer is also working on the development of closed loop criteria for tail sizing criteria of commercial supersonic aircraft using newly developed integrated plant/controller design methodology. The key idea is to rewrite the tail sizing and feedback requirements as Linear Matrix Inequalities. In particular, the effects of feedback specifications, such as MIL STD 1797 Level I and II flying qualities requirements, and of actuator amplitude and rate constraints on the maximum allowable cg travel for a given set of tail sizes were considered. A static state feedback controller was designed as a part of the tail sizing process. This technique is being currently integrated into a tail sizing tool to be used by McDonnell Douglas.

SPACECRAFT ATTITUDE CONTROL AND SMART STRUCTURES: In this program, under the supervision of Professor Agrawal and in response to DoD requirements, the emphasis is on the development of improved control techniques for the attitude control of flexible spacecraft and vibration and shape control using smart structures. Im-

proved control techniques have been developed using the techniques of input shaping in conjunction with PWPF thrusters to minimize structural vibrations. A finite element model has been developed to analyze composite plates with piezoelectric actuators. Analytical techniques to determine optimum actuator voltages to minimize surface error were developed. Smart Structures Laboratory, consisting of vibration isolation platform, space truss, proof mass actuator, fiber optic, shape memory ally, and piezoelectric actuators is under development.

ASTRODYNAMICS: In support of DoD's role to develop advanced concepts in maneuverability for future space missions, Professor Ross' research in astrodynamics is focused on theoretical and numerical aspects of modeling, analysis, simulation, guidance and control of nonlinear dynamical systems such as those encountered in, but not limited to: (1) aerobraking, (2) stability and control of single and dual-spin spacecraft, (3) synergetic maneuvers, and (4) near-Earth-object interception. The research has lead to the development of a refined Energy-Sink theory that has resolved a long-standing debate on the stability of dual-spin spacecraft. In addition, Professor Ross has developed two space maneuvers: one called aerobang that minimizes propellant for orbital plane-changes and another called a singular orbit transfer which achieves suboptimal performance by continuous thrusting. Recent advances have utilized singular optimal control theory to endo-atmospheric space flight, the restricted maximum principle to synergetic maneuvers, and periodic optimal control theory to low-Earth-orbit maintenance. Currently, Professor Ross and his associates are working on developing an advance guidance algorithm for the orbit maintenance of low-Earth-orbiting spacecraft. Research is also continuing on a space mission design project for minimizing energy requirements for deflecting Earth-crossing asteroids.

System Design

MULTI-DISCIPLINARY DESIGN OPTIMIZATION: Under a Cooperative Research & Development Agreement (CRADA) with the McDonnell-Douglas Corporation, Professor Platzer is contributing to the development of advanced multi-disciplinary analysis and design methods for subsonic transport aircraft.

In spacecraft design, under Professor Agrawal's supervision, two design projects were completed. The mission of the first spacecraft was to demonstrate the ability to passively detect, identify and measure the concentration of atmospheric gas constituents to known location of choice on or above the surface of the earth. The second spacecraft had a classified surveillance mission. The Spacecraft bus was designed to meet the payload requirements and also to space qualify advanced technologies.

JOINT STAND-OFF WEAPON CAPTIVE AIR TRAINING MISSLE (JSOW CATM): This project involves the preliminary conceptual development of a Captive Air Training Missile (CATM) to be used in fleet operations for training pilots in the use of the Joint Stand-Off Weapon (JSOW) missile. A Concept of Operations for the CATM has been written, from which functional requirements are to be drawn up. Exploratory work on the conceptual design is to be done in: (1) airframe structural design and weight estimation; (2) aerodynamic analyses for flight loads and contour shaping for minimum drag; (3) flight simulation of the JSOW by the CATM carrier aircraft; and (4) exploration of communications between the CATM on the carrier aircraft and the data link pod on the control aircraft.

AIRCRAFT COMBAT SURVIVABILITY AND AIR DEFENSE LETHALITY ASSESSMENT: Professor Ball originated the study of aircraft combat survivability at NPS in 1974 and has provided technical support for the Naval Air Systems Command (NAVAIR) and the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS): (1) by writing a textbook in aircraft combat survivability ("The Fundamentals of Aircraft Combat Survivability and Design," published by the American Institute of Aeronautics and Astronautics (AIAA) in 1985), (2) by conducting over 15 short (one week) and shorter (three days) courses in survivability since 1978, (3) by developing the NPS/NAVAIR Survivability and Lethality Assessment Center (SLAC), and (4) by conducting a variety of studies on the survivability of U.S. aircraft and the lethality of U.S. air defense systems. In FY 1996, the majority of efforts were devoted to: (1) the continued development of the second edition of the AIAA survivability textbook, and (2) the continued development of the SLAC, primarily through the addition of MOSAIC, a computer program that models the flyout of an infrared

missile toward an aircraft ejecting flares, and three Master's degree studies on the survivability of aircraft. Two of the studies used MOSAIC to study the effects of flare dispensing on the survivability of the P-3 Orion and F-14A Tomcat aircraft against infrared missiles. The third study examined the effects of digital avionics systems on the survivability of modern tactical aircraft.

AIRCREW CENTERED SYSTEM DESIGN (ACSD): The primary focus of the Aircrew-Centered System Design project has been the preliminary definition of attributes and characteristics of ACSD. A working group within AIAA has been established to address ACSD issues and two related sessions were held at the 1st World Congress in Los Angeles. Additional sessions are planned.

SMART STRUCTURES

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force

OBJECTIVE: The goal of this project was to support Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications.

SUMMARY: The major research efforts were in the antenna shape control using piezoceramic sensors and actuators and development of smart structures laboratory. Analytical techniques were developed for optimal placement of piezoceramic actuators for shape control of a cantilever beam. Experiments were performed to validate the analytical techniques. Experimental results showed that the analysis should include hysteresis, nonlinear behavior and effects of transverse stresses. A finite element model is developed to analyze composite plates with pizoelectric actuators. A simple higher order shear deformation theory was developed to improve prediction of plate deformation in comparison to linear theory. Analytical techniques to determine optimum actuator voltages to minimize surface error were developed. Smart Structures Laboratory will be a state-of-the-art laboratory consisting of vibration isolation platform, space truss, proof mass actuator, fiber optic sensor, shape memory alloy, and piezoelectric actuators.

PUBLICATIONS:

Agrawal, B.N. and Bang, H., "Adaptive Structures for Large Precision Antenna," ACTA Astronautics, Vol 38, No. 3, pp. 175-183, 1996.

Agrawal, B.N., "Spacecraft Vibration Suppression Using Smart Structures," Proceedings of Fourth International Congress on Sound and Vibration, pp. 563-570, 24-27 June 996.

Meyer, J.L., Harrington, W.B., Agrawal, B.N., and Song, G., "Application of Piezoceramic to Vibration Suppression of a Spacecraft Flexible Appendage," AIAA 96-3761, AIAA Guidance Navigation and Control Conference, San Diego, CA, 29-31 July 1996.

Agrawal, B.N, Elshafei, M.A., and Song G., "Adaptive Antenna Shape Control Using Piezoelectric Actuators," IAF 96-I.4.02, 47th International Astronautical Congress, Beijing, China, 7-11 October 1996.

THESES DIRECTED:

Treanor, Kirk E., "Performance and Optimal Placement of Piezoceramic Actuators for Shape Control of a Cantilever Beam," Aeronautical and Astronautical Engineer's Thesis, Naval Postgraduate School, June 1996.

Elshafei, M, Adnan, "Smart Composite Plate Shape Control Using Piezoelectric Materials," Aeronautical and Astronautical Ph.D. Dissertation, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Materials, Processes and Structures

KEYWORD: Smart materials, adaptive structures, vibration isolation

SPACECRAFT SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: Fleet Satellite Communications (FLTSATCOM) Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, significant progress has been made in several areas. In FLTSATCOM Laboratory, a Memorandum of Agreement has been signed with Navy Satellite Operation Center (NAVSOC) to upgrade the FLTSATCOM satellite command and telemetry system. In the Spacecraft Attitude Dynamics and Control Laboratory, improved control techniques have been developed for slew maneuvers using the techniques of input shaping in conjunction with PWPF thrusters to minimize structural vibrations. Two spacecraft design projects were completed in response to the request of the sponsor. The mission of the first spacecraft was to demonstrate the ability to passively detect, identify and measure the concentration of atmospheric gas constituents to known location of choice on or above the surface of the earth. The second spacecraft had a classified surveillance mission. The Spacecraft bus was designed to meet the payload requirements and also to space qualify advanced technologies.

PUBLICATION:

Agrawal, B.N., McClelland, and Song, G., "Attitude Control of Flexible Spacecraft Using Pulse-Width Pulse Frequency Modulated Thrusters," IAF 96-A.6.07.

THESIS DIRECTED:

Buck, Nick V., "Minimum Vibrations Maneuvers Using Input Shaping and Pulse-Width Pulse-Frequency Modulated Thruster Control," Aeronautical and Astronautical Engineer's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Spacecraft design, spacecraft attitude control, space manipulator

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School-Institute of Joint Warfare Analysis

OBJECTIVE: The goal of the project was to aid the military communications planners in the challenging task of providing enhanced communications capacity in the environment of shrinking budgets.

SUMMARY: The major effort was to evaluate the ability of the commercial mobile systems (MSS) such as Motorola's Iridium, Loral/Qualcomm's Globalstar, and TRW's Odyssey to satisfy current and anticipate DoD operational requirements. Each of these systems was examined in terms of their capabilities, vulnerabilities, and cost. These systems were found to lack many of the characteristics which contribute to survivability on the battlefield and, ultimately, accomplishment of the mission. Given the proliferation of technology, a relatively unsophisticated adversary could disrupt, deny, or exploit DoD communications transmitted via these systems. These systems, however, can be used for logistic support, morale support, peacekeeping and humanitarian operations as well as military support to civilian authorities.

THESIS DIRECTED:

Haskill, Dana L., "An Analysis of Commercial Low Earth Orbit and Medium Earth Orbit Mobile Satellite Systems and their Potential for Military Use," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Communications satellites, mobile communications, satellite architecture

NAVAL POSTGRADUATE SCHOOL AIRCRAFT SURVIVABILITY SUPPORT

Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS)

OBJECTIVE: The objective of this effort is to continue the technical and educational support provided to the JTCG/AS for the past 23 years by developing educational material, presenting short courses, and conducting research and performing analyses in aircraft combat survivability. The accomplishments during FY96 are given below.

SUMMARY: (1). Educational Materials: Professor Ball continued the development of the second edition of his AIAA textbook, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," published by the American Institute of Aeronautics and Astronautics in 1985, during FY96. Progress in FY96 consisted of improved rough drafts of the Front Material and Chapter 1, "An Introduction to the Aircraft Combat Survivability Discipline." The first rough draft of Chapter 3, "The Missions, the Threats, and the Treat Effects," was prepared.

(2). Research Projects: One project consisted of a study of the current procedures for measuring or quantifying the effectiveness of military weapons systems. Of particular interest was the contribution of survivability to effectiveness. A new procedure for measuring the effectiveness of a system in accomplishing a specified mission was proposed. The procedure uses a hierarchy or tree of system attributes to relate the system attributes to the four key attributes of Availability, Reliability, Survivability, and Capability. Another project was the development of an improved version of MACSAP, version 3.0, a Macintosh SuperCard program for assessing aircraft combat survivability during conceptual design. Several bugs in the version 2.0 were corrected, the flow of the assessment process and the presentation format were improved, and the storage size of the program was significantly reduced.

THESIS DIRECTED:

Bishop, Gary G., "MACSAP 3.0, "Survivability Assessment Software for Aircraft Conceptual Design," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation

KEYWORDS: Aircraft, survivability, design, modeling, simulation, measures of effectiveness

NAVAL POSTGRADUATE SCHOOL/NAVAL AIR SYSTEMS COMMAND SURVIVABILITY AND LETHALITY ASSESSMENT CENTER

Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVES: The objectives of this research project are: (1) to develop and improve the Survivability and Lethality Assessment Center (SLAC) within the NPS Wargaming Analysis and Research Laboratory (WARLAB), and (2) to use the SLAC to conduct survivability and lethality studies. The computer programs in the center are available to the

students and faculty at NPS for research in specific survivability and lethality topics on land, sea, air, and space targets as well as research on the programs themselves.

SUMMARY: The major accomplishments in FY96 were the acquisition and installation of the latest versions of the SURVIAC computer programs for aircraft survivability and the move of the SLAC from the first floor WARLAB to the top floor WARLAB Annex by LT Gary Bishop, and a study by LCDR Ray Collazo of the effects of throttle changes on the miss distance of an infrared missile using MOSAIC.

THESES DIRECTED:

Bishop, Gary G., "Development of a Survivability and Lethality Assessment Center (SLAC) at NPS," Master's, Naval Postgraduate School, September 1996.

Collazo, Ramon A., Jr., "A Study of the Effects of Throttle Changes and Decoy Flares in an Engagement Between an F–14B/D and an AA–11 IR AAM, Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation

KEYWORDS: Aircraft, air defense, survivability, lethality, modeling, simulation, infrared missiles, expendables

STUDIES/RECOMMENDATIONS FOR MEASURES OF EFFECTIVENESS DUE TO AIRCRAFT ON–BOARD ELECTRONIC COUNTERMEASURE EQUIPMENT

Robert E. Ball, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force-Operational Test and Evaluation Center

OBJECTIVES: The objectives of this project are: (1) to study the one-on-one scenario between a surface-to-air, radar guided anti-aircraft missile (SAM) and an aircraft with on-board electronic countermeasures (ECM), (2) to recommend measures of effectiveness (MOEs) relating to the contribution of on-board ECM to aircraft survivability, and (3) to study and recommend suitable operational test and evaluation procedures for ECM equipment.

SUMMARY: This project started in FY95. The progress in FY96 consisted of the initiation of two major studies of the one-on-one scenario between a SAM and an aircraft with on-board ECM. The first study is an examination of the effects of ECM on the closest point of approach, or miss distance, between the SAM and the aircraft. The second study is an examination of the effects of the SAM warhead detonation distance, which is related to the SAM miss distance, on the survivability of the target aircraft. Together, these two studies will determine the increase in aircraft survivability due to on-board ECM. MOEs can be developed using this information. The first phase of both studies will be completed in FY97.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Modeling and Simulation

KEYWORDS: Aircraft survivability, missile lethality, warhead lethality, electronic countermeasures, endgame, test and evaluation

ALTERNATE PROPELLANTS FOR NUCLEAR ELECTRIC PROPULSION

O. Biblarz, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force - Phillips Laboratories

OBJECTIVE: The goal of this project is to relate to the Nuclear Electric Propulsion (NEP) space test mission of the Air Force Phillips Laboratory. Electrical power generation by direct conversion together with electric propulsion are included in a bimodal concept for space nuclear reactor utilization.

SUMMARY: The Space Power and Thermal Management Division of the Air Force Phillips Labs runs a number of programs in which the Naval Postgraduate School is able to contribute expertise. One of these is the TOPAZ II thermionic power generator, purchased from the former U.S.S.R. and being tested and evaluated by the TOPAZ International Program (TIP). Prior to propulsion applications, the thermionic power generator thermal and electric characteristics as well as the system start-up are being studied and these efforts comprised the effort during this reporting period. It was found that useful power can be produced by the thermionic fuel elements at low heating levels. The test stand for single cell elements (TFE) was investigated and critical thermal resistances identified. Work on a control system to be designed to U.S. standards would benefit from the theory and design presented in C.D. Astrin's Master's thesis, "Startup Control of the TOPAZ-II Nuclear Reactor," December 1995.

PUBLICATION:

Biblarz, O., and Bell, W.J., "Thermonic Arc Breakdown," (Submitted)

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Other (Energy Conversion)

KEYWORDS: Nuclear electric propulsion, bimodal, thermionic power generation, nuclear controls

ALTERNATE PROPELLANTS FOR NUCLEAR ELECTRIC PROPULSION

O. Biblarz, Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: The original goal of this project was to relate to the Nuclear Electric Propulsion (NEP) space test mission of the Air Force Phillips Laboratory. Now it is broadened to electrical power generation by direct conversion together with electric propulsion, including space nuclear reactor utilization.

SUMMARY: The Space Power and Thermal Management Division of the Air Force Phillips Labs has run a number of programs for which the Naval Postgraduate School has been able to contribute expertise. One of these is the TOPAZ II thermionic power generator, purchased from the former U.S.S.R. and being tested and evaluated by the TOPAZ International Program (TIP). Prior to propulsion applications, the thermionic power generator thermal and electric characteristics as well as the system start-up are being studied and these efforts comprised the effort during this reporting period. It was found that useful power can be produced by the thermionic fuel elements at low heating levels. The test stand for single cell elements (TFE) was investigated and critical thermal resistances identified. Work on a control system to be designed to U.S. standards would benefit from the theory and design presented in LT Astrin's thesis. In electric propulsion, "thermionic arcing" is proposed as an improvement over present ionization chamber for ion engines.

PUBLICATION:

Biblarz, O., and Bell, W.J., "Thermionic Arc Breakdown in Small Discharge Gaps: Model and Application," accepted for publication in IEEE Industry Applications.

CONFERENCE PRESENTATION:

Biblarz, O., and Bell, W.J., "Thermionic Arc Breakdown," IEEE-IAS Conference, San Diego, CA, 6-10 October 1996.

THESES DIRECTED:

Astrin, C.D., "Startup Control of the TOPAZ-II Nuclear Reactor," Master's Thesis, Naval Postgraduate School, September 1996.

Starling, D.A., "Propellant Feed Control for Ion Engines," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Propulsion and Energy Conversion)

KEYWORDS: Electric propulsion, thermionic power generation, nuclear controls

MEASUREMENT OF SOOT EMISSIONS

O. Biblarz, Professor
D.W. Netzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVES: Adapt an existing three-wavelength laser extinction measurement system for use with a phase conjugate crystal to minimize atmospheric and beam steering effects on soot mass concentration measurements. Use the instrument in conjunction with a recently NPS developed soot mass concentration measurement technique to measure the soot concentration in simulated engine plumes.

SUMMARY: An instrument is under development and calibration capable of on-line determination of soot concentration in plumes. The instrument utilizes an argon-ion laser and two passes through the exhaust plume using a phase conjugate crystal to correct for aberrations in the transmitted beam and to increase accuracy when used in low opacity plumes. Several aspects of instrument layout and performance have been investigated, and an initial calibration was performed using an ethylene-air combustor. The method requires further development, but shows significant promise for use in a jet engine test cell.

THESIS DIRECTED:

Mikeska, D.C., "An Application of Self-Pumped Phase Conjugation for Transmission Measurements in Exhaust Plumes," Aeronautical and Astronautical Engineer, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Soot concentration, plumes, measurement

A FUNDAMENTAL STUDY OF THE COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF FIXED AND ADAPTIVE AIRFOILS

M.S. Chandrasekhara, Research Professor
M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: To study compressibility effects on an airfoil in unsteady motion while it adapts locally to overcome the forces causing unsteady flow separation. The research has applications in active control of helicopter "retreating blade stall." Initiated in April 1994, as a follow-on to the previous research efforts.

SUMMARY: During 1996, the study focused on conducting detailed experimental studies to identify the various mechanisms of dynamic stall onset. Three separate mechanisms were discovered and depending upon flow conditions, these interacted with each other as well. As a means to control these mechanisms, the dynamically deforming leading edge (DDLE) airfoil was designed and fabricated using composite materials after a finite element formulation of the material behavior was completed. Further, a PC-based control system was devised to control the leading edge deformation of the airfoil and thus its leading edge curvature in a precise manner. The systems were fully integrated and evaluated. Preliminary experiments were conducted using a high speed imaging system that was developed in the previous years. Several thousand point diffraction interferograms have been acquired in this phase of the study. Quantitative analysis of these data is about to begin.

PUBLICATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Boundary Layer Tripping Studies of Compressible Dynamic Stall Flow," AIAA Journal, Vol. 34, No. 1, pp. 96-103, January 1996.

Van Dyken, R.D., Ekaterinaris, J.A., Chandrasekhara, M.S., and Platzer, M.F., "Analysis of Compressible Light Dynamic Stall Flow at Transitional Reynolds Numbers," AIAA Journal, Vol. 34, No. 7, pp. 1420-1427, July 1996.

Carr, L.W., and Chandrasekhara, M.S., "Compressibility Effects on Dynamic Stall," Progress in Aerospace Sciences, Vol. 32, pp. 523-573, December 1996.

CONFERENCE PRESENTATIONS:

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "Reynolds Number Influence on 2-D Compressible Dynamic Stall," AIAA Paper 96-0073, AIAA 34th Aerospace Sciences Meeting, Reno, NV, January 1996.

Carr, L.W., Chandrasekhara, M.S., and Davis, S.S. "Flow Control for Unsteady Separated Flow," Proceedings NASA Langley Workshop on Enabling Technologies for Smart Aircraft Systems, Hampton, VA, May 1996.

Chandrasekhara, M.S., Wilder, M.C., and Carr, L.W., "On the Competing Mechanisms of Compressible Dynamic Stall," AIAA Paper 96-1953, AIAA 27th Fluid Dynamics Conference, New Orleans, LA, June 1996.

Platzer, M.F., and Chandrasekhara, M.S., "Research on Dynamic Stall Onset and Stall Flutter," Workshop on Active Blade Vibration Control, Wright Patterson AFB, OH, 14-15 August 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Dynamic stall, helicopter blade stall, interferometry, adaptive wing flow

TESTING OF THREE SPECIAL ARMY AIRFOILS IN THE COMPRESSIBLE DYNAMIC STALL FACILITY

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Aviation Research and Development Center

OBJECTIVE: To study three special airfoils designed by the U.S. Army laboratory for dynamic stall performance under compressible flow conditions.

SUMMARY: This project was initiated in October 1995. The U.S. Army Aviation Research and Development Center, Aeroflightdynamics Directorate has developed three special helicopter blade sections that have shown dramatic performance characteristics under helicopter flight conditions. The Army laboratory is interested in building a helicopter rotor using this blade section profile and test fly the helicopter. However, the performance of the blade sections under dynamic stall conditions, especially at compressible Mach numbers is unknown at this time. The study focused on this aspect. Extensive testing of the airfoils was completed in the NASA Ames compressible dynamic stall facility using point diffraction interferometry. Several hundred interferograms of the flow over a basic RC-608 section, and with two different leading (6 degree and 10 degree) slats were obtained. The improved performance of the rotor blade section is obvious from a qualitative evaluation of the images. The 10 degree slat showed an even superior performance when compared to the 6 degree slat. Quantitative evaluation is ongoing using image processing software developed in-house.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEY WORDS: Stall-free airfoils, flow control

RESEARCH ON AUTONOMOUS AIR VEHICLES

Russell Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this project is to investigate autonomous operation of fixed-wing and rotary-wing aircraft.

SUMMARY: Funding was received and work began on this project during the final quarter of calendar year 1996. During this quarter potential missions for rotary-wing Unmanned Air Vehicles (UAVs) were identified and/or further defined. One mission is a joint program in which a rotary-wing UAV is used to assist a ground based vehicle in the detection, location and disposal of mines and unexploded ordinance. A survey of existing rotary-wing platforms available in the department's UAV lab revealed the need for an intermediate sized platform for initial research.

DoD TECHNOLOGY AREAS: Air Vehicles, Electronics

KEYWORDS: Unmanned air vehicles, avionics, robotics

FAN AND COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

G.V. Hobson, Associate Professor
R.P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division

OBJECTIVE: The overall goal of this continuing project is to validate off-design performance and stall prediction for controlled-diffusion (CD) compressor blading experimentally and thereby enable the development of higher blade-loading designs.

SUMMARY: LDV measurements of the flow through a second-generation CD cascade design were made at three different Reynolds numbers. The second-generation design is for twice the diffusion factor of the first-generation design, and includes an elliptic leading edge. The effect of Reynolds number on the formation of a midchord separation bubble was quantified. It was found that at a low Reynolds number of 210,000 a laminar separation bubble formed over the suction surface. At an intermediate Reynolds number of 380,000 the bubble was transitional, and at the high Reynolds number of 640,000, no midchord separation was evident. However, at the high Reynolds number, trailing edge stall was present as a result of three-dimensional flow developing because of the growth of corner vortices. The structure of the flow was defined using blade-surface pressure measurements, blade-surface flow visualization and laser velocimeter measurements, and was documented in the thesis by Schnorenberg.

PUBLICATIONS:

Moyle, I.N., Shreeve, R.P. and Walker, G.J., "Case Wall Pressures in a Multistage Axial Compressor with Tip Clearance Variation," Journal of Propulsion and Power, Vol 12, No. 5, pp. 967-973, September-October 1996.

Kaul, U.K. and Shreeve, R.P., "Full Viscous Modeling in Generalized Coordinates of Heat Conducting Flows in Rotating Systems," Journal of Thermophysics and Heat Transfer, Vol. 10, No. 4, pp. 621-626, October-December 1996.

Hobson, G.V. and Dober, D.M., "Three-Dimensional Fiber-Optics LDV Measurements in the Endwall Region of a Linear Cascade of Controlled-Diffusion Stator Blades," Accepted for publication in the International Journal of Turbo and Jet Engines.

CONFERENCE PRESENTATIONS:

Hobson, G.V., Ganaim Rickel, H.J. and Williams, A.J.H., "Laser-Doppler Velocimetry and Flow Visualization of Flow Through a Compressor Cascade at Stall," presented at the IGTI/ASME International Turbo Expo '96, Birmingham, UK, 10-13 June 1996, and accepted for publication in the Journal of Turbomachinery.

Hobson, G.V., Wakefield, B.E., and Roberts, W.B., "Turbulence Amplification with Incidence at the Leading Edge of a Compressor Cascade," ASME Paper 96-GT-409 presented at the IGTI/ASME International Turbo Expo '96, Birmingham, UK, 10-13 June 1996.

Hobson, G.V., "Computation of End-Wall Flow in a Linear Cascade and Comparison with Experiment," presented at The Winter Annual Meeting of ASME, San Francisco, CA, 12-17 November 1996.

THESIS DIRECTED:

Schnorenberg, D.G., "Investigation of the Effect of Reynolds Number on Laminar Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Controlled-diffusion blading, LDV measurements, compressor cascade stall.

A COMPARISON OF FLIGHT INPUT TECHNIQUES FOR PARAMETER ESTIMATION OF HIGHLY-AUGMENTED AIRCRAFT

R.M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The objective of this project was to improve the estimation of aerodynamic parameters at high angles of attack by comparing the responses from various classical and modern optimal flight inputs through the use of uncertainty analysis in a parameter-estimation method.

SUMMARY: Recent techniques have been devised for the optimal design of flight inputs for the estimation of stability-and-control derivatives for aircraft at high angles of attack. It was desired to perform a comparison of the results from the new optimal techniques with those of more traditional sequential single-surface inputs. Two optimal input techniques, a single-surface input (SSI) technique using an onboard excitation system, and the classical doublet technique were flown on the F-18 HARV aircraft at the NASA Dryden Flight Research Center. A widely-used parameter-estimation method, pEst, was used for the data analysis and to predict estimations of the Cramer-Rao bounds for each method. The Cramer-Rao bounds provide an estimate of the expected error of the predicted aerodynamic derivatives. It was found that the automated SSI technique provided the smallest Cramer-Rao bounds, and that deflecting each control surface separately significantly decreased the undesirable correlation between the input control surfaces.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Human Systems Interface, Modeling and Simulation

KEYWORDS: Parameter estimation, flight test, parameter identification, highly-augmented aircraft

DEPLOYMENT OF THE APEX AIRCRAFT AT HIGH ALTITUDE

R.M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The meteorological need for atmospheric data at high altitude requires basic aerodynamic data for the design of efficient aircraft able to loiter for extended periods in this extreme environment. The APEX High Altitude Flight Experiment Program is producing a high-altitude testbed aircraft to achieve trimmed flight at altitudes near 100,000 feet to conduct aerodynamic experiments. The proposed launch technique using a balloon lift, vertical drop, and remotely-piloted recovery demands further study to determine the optimum flight profile to achieve flight goals and prevent loss of aircraft. This project is continuing in FY97.

SUMMARY: Six-degree-of-freedom simulation studies were performed to achieve various design points throughout the flight profile, based on chord Reynolds number, Mach number, and lift coefficient. Parameters varied during the studies included release altitude and angle of attack during pullout. Output variables considered included the design conditions as well as descent rates and total time aloft for power budget and system design considerations.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Reynolds number, airfoil, high altitude, simulation, flight mechanics

ON INTEGRATED AIRCRAFT/CONTROLLER DESIGN FOR AUTONOMOUS AIR AND UNDERWATER VEHICLES

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this proposal is to develop a new methodology for integrated aircraft/controller design.

SUMMARY: The methodology developed under this proposal provides aircraft systems designers with a new tool capable of solving the following problem: Given the flying qualities requirements for a specified mission, find the minimum control surface sizes and a feedback controller which together satisfy these requirements. The key approach is to rewrite the flying qualities requirements as Linear Matrix Inequalities.

PUBLICATIONS:

Niewhoener, R.J., and Kaminer, I., "On Integrated Aircraft/Controller Design Using Linear Matrix Inequalities," AIAA Journal of Guidance and Control, Vol. 19, No. 2, pp. 445-452, March-April 1996.

Fryxell, D., Oliveira, P., Pascoal, A., Silvestre, C., and Kaminer, I., "Navigation, Guidance and Control of AUVs: An Application to the MARIUS Vehicle," IFAC Journal of Control Engineering Practice, Vol 4, No 3, pp. 401-409, 1996.

Niewhoener, R.J., and Kaminer, I., "Design of an Autoland Controller for a Carrier Based F-14 Aircraft Using *H_infinity* Output Feedback Synthesis," AIAA Journal of Guidance and Control, Vol. 19, No. 3, pp. 656-663, May-June 1996.

Silvestre, C., Pascoal, A., Kaminer, I., and Hallberg, E., "Trajectory Tracking Controllers for AUVs: An Integrated Approach to Guidance and Control Systems Design," Proceedings of 1996 International Forum on Automatic Control, Vol. Q, pp. 345-350, San Francisco, CA, July 1996.

Kaminer, I., Howard, R.M., and Buttrill, C., "On the Development of the Closed Loop Tail Sizing Criteria for HSCT," Proceedings of 1996 AIAA Conference on Guidance, Navigation and Control, P 96-3861, San Diego CA, August 1996.

CONFERENCE PRESENTATIONS:

Kaminer, I., "Design of Integrated Guidance and Control Systems for Unmanned Air Vehicles," presented at Purdue University, Lafayette, IN, April 1996.

Kaminer, I., "Integrated Guidance and Control of Autonomous Vehicles with UAV and AUV Applications," presented at the National Defense Research Establishment (FOA), Stockholm, Sweden, May 1996.

Kaminer, I., "Plant/Controller Optimization," two lectures presented at the National Defense Research Establishment (FOA), Stockholm, Sweden, May 1996.

Kaminer, I., "On the Development of Closed Loop Tail Sizing Criteria for HSCT," presented at McDonnell-Douglas, Long Beach, CA, 6 August 1996

DoD KEY TECHNOLOGY AREAS: Other (Aircraft Control Power, Feedback Control)

KEYWORDS: Feedback systems, control power, linear matrix inequalities

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE AIR TRAINING MISSILE (CATM) CONCEPTUAL DESIGN

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform conceptual design studies on a captive air training missile for the JSOW Unitary Missile and to explore the possibility of extending its applicability to other missiles.

SUMMARY: This project was responsible for the issues related to the JSOW CATM avionics system and for the development of cockpit steering commands requirements for the carriage aircraft. The work accomplished includes development of the preliminary functional requirements for JSOW CATM avionics as well as development of JSOW 6DOF nonlinear simulation and guidance and control system for a typical JSOW profile.

THESIS DIRECTED:

Reilly, D.J., "Unitary Joint Standoff Captive Air Training Missile Avionics Design through Operational Concepts and Functional Requirements Analysis," Master's Thesis, Naval Postgraduate School, March 1996.

Wagner, D.R., "Unitary Joint Standoff Weapon Captive Air Training Missile Flight Simulation," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Stand-off Weapons, Avionics)

KEYWORDS: JSOW CATM, avionics, guidance and control

ON DESIGN AND IMPLEMENTATION OF NONLINEAR GAIN-SCHEDULED CONTROLLERS FOR MANNED AND UNMANNED VEHICLES

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School and 1994-1995 NATO Fellowship

OBJECTIVE: The goal of this project is to develop efficient techniques for designing and implementing gain-scheduled controllers for nonlinear plants. In particular, we are interested in the designing of trajectory tracking controllers for autonomous underwater and air vehicles.

SUMMARY: The work covered by this proposal addresses the problem of integrated design of guidance and control systems for autonomous vehicles (AVs). In fact, we have developed a new methodology for integrated design of guidance and control for autonomous vehicles. The methodology proposed leads to an efficient procedure for the design of controllers for AVs to accurately track reference trajectories defined in an inertial reference frame. This methodology was applied to the design of a tracking controller for the Unmanned Air Vehicle Bluebird at the NPS UAV Lab and to the Autonomous Underwater Vehicle Marius at the Instituto Superior Tecnico of Lisbon, Portugal.

PUBLICATIONS:

Fryxell, D., Oliveira, P., Pascoal, A., Silvestre, C., and Kaminer, I., "Navigation, Guidance and Control of AUVs: An Application to the MARIUS Vehicle," to appear in the March issue of IFAC Journal of Control Engineering Practice, 1996.

Niewhoener, R.J., and Kaminer, I., "Design of an Autoland Controller for F-14 Aircraft Using H_infinity Synthesis," to appear in AIAA Journal of Guidance and Control.

Niewhoener, R.J., and Kaminer, I., "On Integrated Aircraft/Controller Design Using Linear Matrix Inequalities," to appear in AIAA Journal of Guidance and Control.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Unmanned Air Vehicles)

KEYWORDS: Flight control systems, gain-scheduled controllers, nonlinear control, robust control, guidance and control

MARITIME AVIONICS SUBSYSTEMS AND TECHNOLOGY PROGRAM (MAST)

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform research and development in advanced avionics technology topics relevant to NAVAIR MAST program

SUMMARY: Over the past several years under NAVAIR sponsorship NPS has embarked on the development and evaluation of GPS/INS integration systems. In particular, progress has been made in the development of the uniform framework for the INS/GPS integration using Kalman Filtering. The work is ongoing and strives to unify various approaches to the development of INS systems and their integration with GPS using Kalman Filtering.

THESIS DIRECTED:

Zanino, J.A., "Uniform System for the Rapid Prototyping and Testing of Controllers for Unmanned Aerial Vehicles," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation; Other (Avionics)

KEYWORDS: GPS, inertial navigation, Kalman filtering, rapid prototyping

ON DEVELOPMENT OF HIGH SPEED CIVIL TRANSPORT (HSCT) TAIL SIZING CRITERIA

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration-Langley Research Center

OBJECTIVE: To develop tail sizing criteria for high speed civil transport, (HSCT).

SUMMARY: This work was done as a part of National Aeronautics and Space Administration/American Society for Engineering Education (NASA/ASEE) Summer Faculty Fellowship Program. It determined the HSCT tail sizing criteria using newly developed integrated aircraft/controller design methodology (the methodology was developed together with Ph.D. student R. Niewoehner). The key idea was to rewrite the tail sizing and feedback requirements as Linear Matrix Inequalities. In particular, the effects of feedback specifications, such as MIL STD 1797 Level I and II flying qualities requirements, and of actuator amplitude and rate constraints on the maximum allowable cg travel for a given set of tail sizes were considered. A static state feedback controller was designed as a part of the tail sizing process.

DoD KEY TECHNOLOGY AREAS: Other (Flight Controls)

KEYWORDS: Tail sizing, robust control, optimization

LETHAL UNMANNED AIR VEHICLES FEASIBILITY STUDY

I.I. Kaminer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: Investigate the feasibility of using Unmanned Air Vehicles (UAVs) to detect and destroy mobile missile launchers.

SUMMARY: In the recent study conducted by Professor Marshal of the Department of Operations Research at NPS, the authors have shown that the most effective way to deal with ballistic missiles (like the SCUDS used by Iraq in the Gulf War) is to destroy the mobile missile launchers before the missile is launched. Motivated by these results, a SIMULINK/MATLAB simulation was developed to study the technical issues involved in using UAVs to accomplish this task. Furthermore, a survey of existing UAV systems was conducted to identify a platform most suitable to detect and destroy mobile missile launchers.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Other (Unmanned Air Vehicles)

KEYWORDS: Lethal UAVs, guidance and control

A SHORT COURSE IN STRENGTH AND FATIGUE OF AIRCRAFT STRUCTURES

Gerald H. Lindsey, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To develop a short course in Aircraft Structural Strength and Fatigue with all of the teaching materials and student handouts needed to teach the course.

SUMMARY: Beginning with interviews of key structures competency personnel at NAVAIR and airframe manufacturers, a list of preferred subjects was developed. Using it as a base, a syllabus for a two week short course was developed and approved by NAVAIR. The format of the course included both lectures and workshop sessions each morning and each afternoon to provide hands-on experience in working problems in the field and to break up the theory periods to refresh the students. A total of thirty hours of lecture and thirty hours of structured problem sessions will be presented.

An extensive review of the library databases was conducted for texts in the field, and nine were selected for in-hand evaluation. From this process a text was selected and supplemental references were acquired for use during the class and afterwards by the participants.

Outlines for each topic in the syllabus have been prepared and a part of the work of preparation of the visuals and student hand-out materials has been completed. This project will be followed with one in 1997 to complete the work of preparation, and the first class of twenty is now scheduled to be taught in March 1997.

OTHER: A complete set of all support materials such as graphs, charts, tables, illustrations, lecture outlines, syllabus, etc. will be provided for each student in printed form.

DoD KEY TECHNOLOGY AREAS: Manpower, Personnel and Training

KEYWORDS: Aircraft fatigue, metal fatigue, fracture mechanics, crack propagation, strength theories.

JOINT STAND-OFF WEAPON (JSOW) UNITARY CAPTIVE AIR TRAINING MISSILE (CATM) CONCEPTUAL DESIGN STUDIES

Gerald H. Lindsey, Professor
Oscar Biblarz, Professor
Isaac Kaminer, Assistant Professor
Sandra Scrivener, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: To perform conceptual design studies on a Captive Air Training Missile to be used by F-18 pilots in training for use of the JSOW Unitary missile.

SUMMARY: A detailed concept for operational employment of the JSOW CATM has been written, from which functional requirements for the CATM have been derived. These include all operational, performance, compatibility, communications and electro-mechanical requirements and constraints.

Detailed studies have been made in four areas: (1) overall configuration studies, (2) airframe structural weight, strength and fatigue studies, (3) configuration drag studies of the missile and pylon while in the captive position, and (4) flight simulation studies of the missile in flight after release. Configuration studies have led to a preferred size and carry position to accommodate weight limitations and constraints created by requirements to communicate with the GPS satellites and the control aircraft. Weight, strength and fatigue studies have shown that a gross weight of 300 pounds may be possible, but will be a difficult challenge to achieve. Drag studies have resulted in new insights into the process of tailoring the aft area distribution of the CATM for minimum drag and have led to a promising approach to optimizing the configuration design. Flight simulation studies have been completed for the missile itself, and work is now continuing by modeling the F-18 to fly as the JSOW in the carry mode as the training aircraft and determining the best suite of pilot cues to accomplish it.

THESES DIRECTED:

Reilly, D.J., "Unitary Joint Standoff Captive Air Training Missile Avionics Design through Operational Concepts and Functional Requirements Analysis," Master's Thesis, Naval Postgraduate School, March 1996.

Formet, G.L., "Conceptual Design Definition of a JSOW Unitary CATM," Master's Thesis, Naval Postgraduate School, June 1996.

Scarry, M.T., "JSOW CATM Conceptual Weight and Airframe Design," Master's Thesis, Naval Postgraduate School, September 1996.

Wagner, D.R., "Unitary Joint Standoff Weapon Captive Air Training Missile Flight Simulation," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Conventional Weapons

KEYWORDS: Missile, missile design, CATM, JSOW, pilot training

FLOW BEHAVIOR IN FASTHAWK COMBUSTOR GEOMETRIES

D.W. Netzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: To determine the effects of geometry on the flow and mixing characteristics of FASTHAWK combustors.

SUMMARY: A water tunnel study was conducted in support of the FASTHAWK combustor design. Five combustion chamber configurations (including a combustion can, aerogrid, turbulator and swirl devices at the dump plane) were evaluated with laser Doppler velocimetry to measure profiles of turbulence intensity and axial velocity. Laser sheet flow visualization was used to analyze flow patterns of seven different combustion can designs and nozzle exit swirl. The baseline, swirl, and aerogrid configurations produced similar flow characteristics, moderate turbulence intensity and a large primary recirculation zone. The latter was unsuitable for short (L/D<1.0) combustors. The combustion can and turbulator configurations were similar to one another with respect to axial velocity profiles and both produced a primary recirculation zone with L/D significantly less than 1.0. The turbulator configuration also produced significantly higher turbulence intensities throughout the combustion chamber, greater than any of the other configurations. The evaluation of the combustion can designs revealed the greatest impact on flow patterns results from the axial location of hole rows and that fuel injection is optimum when done near the downstream end of the primary recirculation zone.

THESIS DIRECTED:

Dunigan, T.J., "A Study of the Effects of Geometric Variations on the Flow Characteristics in the FASTHAWK Combustor Chamber," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Ramjet combustors, flow measurements

PARTICULATE AND MIXING EFFECTS ON PLUME AFTERBURNING SUPPRESSION

D.W. Netzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsors: Office of Naval Research and the Naval Postgraduate School

OBJECTIVE: To quantify the effects of solid propellant rocket motor exhaust particulates and nozzle geometry on the suppression of plume afterburning and to obtain effective nozzle geometries which do not adversely effect thrust.

SUMMARY: Experimental investigations were conducted to determine the expected behavior of burning aluminum droplets in rocket motors and the effects of particle loading and nozzle shapes used for enhanced plume mixing on the plume particle size distribution. Burning large aluminum particles, free-falling with gravity acceleration at atmospheric pressure will usually break up or shed lobes during or at the end of burning to produce multiple aluminum oxide fragments with diameters between 10% and 40% of the initial diameter. Single-particle and ensemble measurements in the plume were made using a micromotor mounted on a thrust stand. For both minimum-smoke and highly aluminized propellants the larger particles are concentrated along the plume centerline, in qualitative agreement with code predictions which treat nozzle flows without particle breakup or collision coalescence. For these propellants enhanced mixing nozzle shapes were found to increase the maximum particle size that is distributed throughout the plume from approximately 3 Km to 5-6 Km. Nozzle geometries were designed which were effective for reducing afterburning without significant thrust degradation.

PUBLICATIONS:

Hill, J.A., Ruttenberg, E.C. and Netzer, D.W., The Behavior of Particulate in Rocket Motor Chambers and Plumes with Conventional and Enhanced Mixing Nozzles," Proceedings of the Ninth ONR Propulsion Meeting, pp. 3-15, 1996.

Ruttenberg, E.C. and Netzer, D.W., "Aluminum Particle Breakup in Combustion Environments," submitted to J. Propulsion and Power.

Hill, J.A. and Netzer D.W., "Spatial Variations in Aluminum Oxide and Zirconium Oxide Particle Sizes in Rocket Plumes," submitted to J. Propulsion and Power.

Schadow, K.C., Yu, K.H. and Netzer D.W., "Exhaust Plume Characterization and Control," to appear in Modern Developments in Propulsion and Combustion, Taylor and Francis.

CONFERENCE PRESENTATIONS:

Hill, J.A., Ruttenberg, E.C. and Netzer, D.W., "The Behavior of Particulate in Rocket Motor Chambers and Plumes with Conventional and Enhanced Mixing Nozzles," Ninth ONR Propulsion Meeting 1996, 9-12 September 1996, Alexandria, VA.

THESES DIRECTED:

Ruttenberg, E.C., "Burning Characteristics of Individual Aluminum/Aluminum Oxide Particles," Master's Thesis, Naval Postgraduate School, June 1996.

Hill, J.A., "Particulate Characteristics and Effects in Solid Rocket Motor Plumes," Master's Thesis, Naval Postgraduate School, June 1996 (SECRET/NOFORN).

Fadler, D.C., "Tactical Missile Plume Particulate Effects on Infrared Suppression Techniques ," Master's Thesis, Naval Postgraduate School, December 1996 (SECRET/NOFORN)

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Rocket plumes, mixing, particulates, afterburning

PERFORMANCE OPTIMIZATION FOR LIQUID-FUEL RAMJETS

D.W. Netzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVES: To determine optimum inlet dump configurations with and without the use of aerogrids. To evaluate the combustion characteristics of new, high energy-density fuels and fuel additives.

SUMMARY: Four variations of a single-side inlet-dump ramjet combustor were examined using laser Doppler velocimetry and laser sheet flow visualization in a water tunnel. Aerogrids were found to reduce the size of recirculation zones, eliminate the large-scale vortices shed from the inlet dump and increase fine-scale mixing. These effects should result in increased combustion efficiency and minimum combustion instability, but at the expense of narrower flammability limits and increased pressure losses. Two different scalloped inlets were investigated for providing the benefits of the aerogrid with reduced disadvantages. A geometry which produced high-amplitude, low frequency flow structures showed promise but further optimization is required. The burning rates and characteristics of several high energy liquid fuels, including JP-10, RJ-7, Mobil E-5 and JP-8, and of high-octane, high flash point solvents were determined using a windowed combustion bomb at pressures from 1-10 atm, a video camera and a frame grabber. Atomization characteristics were measured using a poppet atomizer and a Malvern particle analyzer. Mobil E-5 and RJ-7 had higher burning rates and higher volumetric heating rates than JP-10. The solvents had adequate burning rates, but increased sooting characteristics due to high C/H ratios. Smoke suppressant additives may improve the overall performance of these solvents. 0.6% by volume of an inexpensive, commercially available fuel additive in kerosene was found effective for reducing plume IR signature in a motor burning kerosene and oxygen. At an equivalence ratio of 2.0 and a pressure of 1.4 MPA the plume soot concentration was reduced by 65% and the average plume radiance by 82% in the 3.5-5μ band. The size distribution and optical properties of the soot were not significantly altered. Combustion efficiency was maintained between 93-96%.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Ramjet combustors, inlets, fuel performance

AIRCREW-CENTERED SYSTEM DESIGN

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: Define the attributes and characteristics of an Aircrew-Centered System Design discipline.

SUMMARY: A number of recent initiatives have been implemented to alleviate problems which arise as modern tactical aircraft and cockpits have come to overwhelm the aircrew. Further initiatives have been identified to further ameliorate aircrew work and/or information overload. These recent and future initiatives are briefly summarized herein: 1) An initiative is underway to create an Aircrew-Centered System Design Technical Committee within the American Institute of Aeronautics and Astronautics (AIAA) which will focus professional attention on the impact of aircrew system requirements on the conceptual, preliminary and detailed design, flight test and operation of aircraft, 2) Two two-hour sessions were held on Aircrew-Centered System Design at the 1st World Aviation Congress held in Los Angeles, California on October 22-24, 1996: "Foundations of Aircrew-Centered System Design;" and "Applications of Aircrew-Centered System Design." A total of seven papers were presented in these two sessions, 3) Three two-hour sessions on Aircrew-Centered System Design are scheduled for the 2nd World Aviation Congress being held in Anaheim, California, on October 13-16, 1997. Separate sessions will be devoted to sensors, human factors and cockpit design. A total of twelve papers are expected to be presented in these three sessions, and 4) One two-hour session concerning Aircrew-Centered System Design is scheduled for the 36th Aerospace Sciences Meeting being held in Reno, Nevada on January 12-18, 1998. Eight papers are expected to be presented in this session.

THESIS DIRECTED:

Gibson, G.J., "Aircrew-Centered System Design Analysis Considerations for the MH-53E Helicopter," Master's Thesis, Naval Postgraduate School, December 1996.

Bauer, D.O., "Historical Perspective of Aircrew System Effectson Aircraft Design and Performance," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Other (Integrated system design)

KEYWORDS: Aircrew, design integration, system design

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION / UNIVERSITY ADVANCED DESIGN PROGRAM IN AERONAUTICS (NASA/USRA) AT THE NAVAL POSTGRADUATE SCHOOL

Conrad F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The goal of the NASA/USRA University Advanced Design Program in Aeronautics is to improve and enhance aeronautical design instruction at the Naval Postgraduate School.

SUMMARY: The primary focus of the advanced design program of instruction is the innovative design of deck-launched waverider-configured aircraft. However, due to student interest, conventional aircraft, helicopter, aircraft engine and missile system design projects were also completed. Automated design tools were developed. Student aircraft and helicopter design products were entered in national competitions. Research efforts involving interplanetary waverider-configured spacecraft using aero-gravity-assist and the LoFlyte (M=5) waverider configuration supported

design class projects. One color printer, several design reference textbooks and several small miscellaneous pieces of computer hardware were purchased to enhance the quality and effectiveness of the design laboratory supporting aircraft, missile, engine and helicopter aeronautical design.

THESES DIRECTED:

Kenny, A.M., Jr., "Low-Speed Water Tunnel Flowfield Visualization Studies of the Hypersonic LoFlyte Waverider Configuration," Master's Thesis, Naval Postgraduate School, September 1996.

Flynn, J.M., "Optimization and Performance Analysis of Waverider Configured Interplanetary Space Vehicles," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Integrated system design)

KEYWORDS: Waverider, strike, design integration, subsonic, supersonic, aerodynamic testing and hypersonic

AIRCREW-CENTERED SYSTEM DESIGN

C.F. Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: Define the attributes and characteristics of an Aircrew-Centered System Design discipline.

SUMMARY: A number of recent initiatives have been implemented to alleviate problems which arise as modern tactical aircraft and cockpits have come to overwhelm the aircrew. Further initiatives have been identified to further ameliorate aircrew work and/or information overload. These recent and future initiatives are briefly summarized herein.

An initiative is underway to create an Aircrew System Design Technical Committee within the American Institute of Aeronautics and Astronautics (AIAA) which will focus professional attention on the impact of aircrew system requirements on the conceptual, preliminary and detailed design, flight test and operation of aircraft.

DoD KEY TECHNOLOGY AREAS: Other (Integrated system design)

KEYWORDS: Aircrew, design integration, system design.

HIGH LIFT STUDIES FOR ENHANCED FIGHTER MANEUVERABILITY

M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School

OBJECTIVE: Identify promising methods for the generation and exploitation of dynamic lift in order to achieve enhanced fighter aircraft maneuverability. To this end, perform detailed experimental studies on double delta wings and canard-wing configurations.

SUMMARY: Water tunnel flow visualization studies were conducted to determine the effect of Reynolds number on the vortex development over cropped double-delta wings.

PUBLICATION:

Hebbar, S.K., Alkhozam, A.M., Platzer, M.F., "Experimental Study of Vortex Flow Control on Double-Delta Wings Using Fillets," Journal of Aircraft, Vol. 33, No. 4, pp. 743-751, July-August 1996.

CONFERENCE PRESENTATION:

Hebbar, S.K., Chang, W., Platzer, M.F., "Juncture Fillets for Vortex Flow Control on Double-Delta Wings Undergoing Sideslip," AIAA Paper 96-0663, 34th Aerospace Sciences Meeting, Reno, NV, 15-18 January 1996.

THESES DIRECTED:

Fritzelas, A., "A Water Tunnel Investigation of the Reynolds Number Effect on High-Incidence Flow over Double-Delta Wings," Master's Thesis, Naval Postgraduate School, March 1996.

LeTourneau, M.A., "Evaluation of the Boeing PANAIR Technologies Code (A502I) through Prediction of Separation Forces on the GBU-24," Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Other (Aerodynamics)

KEYWORDS: High-lift aerodynamics, vortical flows

NUMERICAL INVESTIGATION OF HIGH ANGLE OF ATTACK MISSILE AERODYNAMICS

M.F. Platzer, Distinguished Professor
I.H. Tuncer, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: Develop Navier-Stokes and panel code solutions for the vortical flow over complete missile configurations in steady or maneuvering high angle of attack flight.

SUMMARY: Navier-Stokes computations were completed for subsonic flow over a complete missile configuration at high angle of attack using the NASA-Ames OVERFLOW code. Also, the NASA-Ames panel code PMARC was extended to compute the flow over bodies of revolution at high angle of attack.

PUBLICATIONS:

Van Dyken, R.D., Ekaterinaris, J.A., Chandrasekhara, M.S., Platzer, M.F., "Analysis of Compressible Light Dynamic Stall Flow at Transitional Reynolds Numbers," AIAA Journal, Vol. 34, No. 7, pp. 1420-1427, July 1996.

Tuncer, I.H., and Platzer, M.F., "Thrust Generation due to Airfoil Flapping," AIAA Journal, Vol. 34, No. 2, pp. 324-331, February 1996.

CONFERENCE PRESENTATIONS:

Tuncer, I.H., Marvin, R., Platzer, M.F., "Numerical Investigation of Subsonic Flow over a Typical Missile Forebody," AIAA Paper 96-0189, 34th Aerospace Sciences Meeting, Reno, NV, 15-18 January 1996.

Lambert, M., and Platzer, M.F., "Evaluation of the NASA Ames Panel Method (PMARC) for Aerodynamic Missile Design," AIAA Paper 96-0775, 34th Aerospace Sciences Meeting, Reno, NV, 15-18 January 1996.

Van Dyken, R.D., Yu, K., Gutmark, E., Tuncer, I., Platzer, M.F., McLachlan, B., Bell, J., "Passive Control of Flow Separation over Delta Wings at High Angle of Attack," AIAA Paper 96-0661, 34th Aerospace Sciences Meeting, Reno, NV, 15-18 January 1996.

DoD KEY TECHNOLOGY AREAS: Other (Aerodynamics)

KEYWORDS: Missile aerodynamics, vortical flows, computational fluid dynamics

EXPERIMENTAL STUDY OF BOUNDARY LAYER ENERGIZATION

M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: The objective of the proposed effort is the exploration and demonstration of a new boundary layer acceleration and flow control device.

SUMMARY: Water tunnel tests showed that the use of flapping airfoils is a promising method of suppressing flow separation.

CONFERENCE PRESENTATIONS:

Jones, K.D., Dohring, C.M., Platzer, M.F., "Wake Structures Behind Plunging Airfoils: A Comparison of Numerical and Experimental Results," AIAA Paper 96-0078, 34th Aerospace Sciences Meeting, Reno, NV, 15-18 January 1996.

Dohring, C.M., Platzer, M.F., Jones, K.D., Tuncer, I.H., "Computational and Experimental Investigation of the Wakes Shed from Flapping Airfoils and their Wake Interference/Impingement Characteristics," Paper No. 33, 78th AGARD Fluid Dynamics Symposium, Trondheim, Norway.

THESES DIRECTED:

Ortiz, M.A., "Numerical Simulation of the Flow Field about a Multi-Element Airfoil with Oscillating Flap," Master's Thesis, Naval Postgraduate School, March 1996.

Dohring, C.M., "Experimental Analysis of the Wake of an Oscillating Airfoil," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Other (Aerodynamics/Hydrodynamics)

KEYWORDS: Drag reduction, flow control, boundary layers

ADVANCED MULTIDISCIPLINARY ANALYSIS AND DESIGN OPTIMIZATION METHODS FOR SUBSONIC TRANSPORT AIRCRAFT

M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: McDonnell-Douglas Aircraft Company

OBJECTIVE: To contribute to the development of advanced multidisciplinary analysis and design optimization methods for subsonic transport aircraft.

SUMMARY: This work entails the use/extension of three-dimensional computational fluid dynamics codes for viscous subsonic/transonic flow over a wing/body/nacelle/pylon configuration and the development of new turbulence models. Also, it involves the use of a finite element code to determine the aircraft deformation under loading and to speed up the computations by means of parallelization.

PUBLICATION:

Jones, K.D., and Platzer, M.F., "Time-Domain Analysis of Low-Speed Airfoil Flutter," AIAA Journal, Vol. 34, No. 5, pp. 1027-1033, May 1996.

DoD KEY TECHNOLOGY AREAS: Other (Aerodynamics/Structures)

KEYWORDS: Aerodynamics, computational fluid dynamics, structures, finite element modelling, design optimization

AIRFOIL STALL INVESTIGATIONS

M.F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Unfunded

OBJECTIVE: To develop computational methods for the analysis of stall onset on airfoils and turbomachinery blades

SUMMARY: Navier-Stokes were developed which showed that the incorporation of boundary transition is the key to the computation of separation bubbles and of dynamic stall phenomena on airfoils and turbomachinery blades.

PUBLICATIONS:

Ekaterinaris, J.A., and Platzer, M.F., "Numerical Investigation of Stall Flutter," ASME Journal of Turbomachinery, Vol. 118, pp. 197-203, April 1996.

Ekaterinaris, J.A., and Platzer, M.F., "Effects of Turbulence Modelling and Transition on the Numerical Prediction of Dynamic Stall," Engineering Turbulence Modelling and Experiments, Elsevier Publishing Company, pp. 707-718, 1996

CONFERENCE PRESENTATIONS:

Sanz, W., and Platzer, M.F., "On the Navier-Stokes Calculation of Separation Bubbles with a New Transition Model," ASME 96-GT-487, 41st International Gas Turbine Congress, Birmingham, UK, 10-13 June 1996.

Luecke, J.R., Benetschik, H., Sanz, W., Gallus, H.E., Platzer, M.F., "Numerical Investigation of Transition and Hub Corner Stall Phenomena Inside an Annular Compressor Cascade," AIAA Paper 96-2655, 32nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, 1-3 July 1996.

THESIS DIRECTED:

Margason, R.J., "Investigation of the Effect of Two-Dimensional Cavities on Boundary Layers in an Adverse Pressure Gradient," Ph.D. Dissertation, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Other (Aerodynamics)

KEY WORDS: Viscous flow aerodynamics, dynamic stall, turbomachinery aerodynamics

AIR DEFENSE SYSTEM INTEGRATOR (ADSI) AND MULTI-SOURCE TACTICAL SYSTEM (MSTS) SYSTEMS ANALYSIS

I.M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force Space Command

OBJECTIVE: This three-year project was aimed at analyzing the Air Defense System Integrator (ADSI) and the Multi-Source Tactical System (MSTS) in support of the warfighter.

SUMMARY: This year covers the final stage of a three-year contract. As in any multi-year contract, most of the work was performed in the prior years. The 1994 and 1995 Research Summaries outline these efforts. In compliance with the wishes of the sponsor, the tasks for FY96, were re-defined to investigate topics in space warfare, vis-a-vis their relationship to student participation by way of projects and theses. As a result, a space warfare research program home page was established in a cooperative effort with Air Force Institute of Technology (AFIT). The URL is given by http://dubhe.cc.nps.navy.mil/~swrp. This is also hot-linked to corresponding home pages at AFIT: http://www.afit.af.mil/Schools/EN/ENY/people/chall/courses/seng631/project. A significant part of the effort was also directed towards the logistic problems pertaining to establishing a joint space warfare research program (with AFIT).

OTHER: Electronic home page(s) created jointly with Space Operations Curriculum students that graduated in September 1996. The URL is at: http://dubhe.cc.nps.navy.mil/~swrp.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Command, Control and Communications

KEYWORDS: Warfighter, advanced concepts, space applications

NEAR-EARTH-OBJECT INTERCEPTION

I.M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Applied Physics Laboratory, Johns Hopkins University

OBJECTIVE: This proposal is for the purpose of analyzing certain space warfighting problems associated with the threat from near-Earth-objects.

SUMMARY: This is a multi-year ongoing project. A comprehensive analysis was performed on the dynamics and control of deflecting near-Earth objects (i.e., those asteroids and comets that intersect the orbit of Earth). This analysis is contained in the Hall-Ross report that was delivered to Space Warfare Center (SWC) in March 96. Two new student theses are currently being directed by the PI. An extensive numerical optimization of impulsive maneuvers has been performed leading to the conclusion that there may be alternative minimum-energy missions that might accomplish the task of planetary defense. This has lead to a more well-defined road map for the outyears. Plans are underway to investigate how this effort may complement the Clementine-II mission.

THESIS DIRECTED:

Elder, Jeffrey T., "Impulse Optimization for Short Period Response to Asteroid Impact Hazards," Master's Thesis, Naval Postgraduate School, December 1996.

OTHER: Hall, C.D. and Ross, I.M., "Dynamics and Control Problems in the Deflection of Near-Earth Objects," Report of the SWC/AFIT/NPS Space Warfare Research Program, March 1996.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Asteroids, comets, hazard mitigation

AEROBRAKING

I.M. Ross, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force

OBJECTIVE: This proposal is for the purpose of analyzing aerobraking maneuvers associated with the design of future spacecraft. These maneuvers will be analyzed for their tactical utility to the military, and the driving design parameters will be determined.

SUMMARY: A synergetic maneuver has the potential to enhance the tactical utility of military space. The maneuver requires a winged spacecraft. In 1996, new necessary conditions were obtained for the optimal synergetic maneuver. In addition, work on the singular thrust program shows that for flight occurring at orbital conditions, the optimal angle of attack is not at the maximum lift-to-drag ratio, but given by a transcendental equation. Numerical work performed elsewhere validates this conclusion to the extent that higher angles of attack yield larger synergetic efficiency.

PUBLICATIONS:

Ross, I.M., "Extremal Angle-of-Attack Over a Singular Thrust Arc in Rocket Flight," to appear in the Journal of Guidance, Control and Dynamics, Vol. 20, No. 2, March-April 1997.

Ross, I.M., "An Analysis of First-Order Singular Thrust-Arcs in Rocket Trajectory Optimization," to appear in Acta Astronautica.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Synergetic maneuvers, spacelift

TRANSONIC FAN DESIGN VALIDATION

R.P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center-Aircraft Division and National Aeronautics and Space Administration

OBJECTIVE: This is continuing project to replace the single-stage fan currently installed in the transonic compressor test rig at the NPS Turbopropulsion Laboratory with a new stage designed by NASA with current CFD methods, and to evaluate all aspects of the aerodynamic performance using advanced intrusive and non-intrusive measurement techniques. The goals are to provide code vs. measurement comparisons using the new stage, to document a design-and-test case study for instructional purposes, and to develop a working facility and diagnostics for future studies.

SUMMARY: The transonic compressor test rig has been reactivated and operated successfully to 20,000 RPM. The desig speed of the new rotor is 27,000 RPM. Since the front compressor bearing is showing high temperature and 1/ Rev vibrations, balancing is required and this will be done with the new rotor installed. New VXI-bus data acquisition hardware was installed and software generation was initiated using HP-VEE. Significant progress was made in developing the pressure-sensitive paint (PSP) technique to map rotor surface pressures. A high-speed turbine drive unit was installed and used to obtain phase-locked PSP data from a rotor operating at 20,000 RPM. Clearly defined in these tests was the temperature sensitivity of the paint technique. The turbine rotor is to be used to develop a procedure to identify surface pressure and temperature from phase-locked images.

PUBLICATION:

Sanger, N.L., "Design of a Low Aspect Ratio Transonic Compressor Stage Using CFD Techniques," Journal of Turbomachinery, Vol. 118, pp. 479-491, July 1996.

CONFERENCE PRESENTATIONS:

Gamerdinger, P.M., and Shreeve, R.P., "The Effects of Low-Profile Vortex Generators on Flow in a Transonic Fan-Blade Cascade," AIAA 96-0250, presented at the AIAA 34th Aerospace Sciences Meeting and Exhibit, Reno, NV, 15-18 January 1996.

Seivwright, D.L., and Shreeve, R.P., "Flat Plate in a Highly-Underexpanded Sonic Jet," AIAA 97-0066, presented at the AIAA 35th Aerospace Sciences Meeting and Exhibit, Reno, NV, 6-10 January 1997.

THESIS DIRECTED:

Seivwright, D.L., "Application of Pressure-Sensitive Paint in Shock-Boundary Layer Interaction Experiments," Master's Thesis, Naval Postgraduate School March 1996.

Quinn, Kevin J., "Pressure-Sensitive Paint Measurement Technique Development for Turbomachinery Application," Engineer's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Transonic compressor stage design, compressor design validation, transonic compressor test, pressure-sensitive paint.

UNMANNED AIR VEHICLE (UAV) GAS TURBINE PROPULSION ASSESSMENT

R.P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Unmanned Aerial Vehicles Joint Program Office

OBJECTIVE: To conduct a program to provide information on the performance of small gas-turbine engines, and to generate the means to assess the potential for using gas turbines in UAVs.

SUMMARY: A small gas-turbine engine test rig was built and used to evaluate the performance of a commercially-available, 17 pounds thrust engine. A performance code was used to simulate the measured performance and thereby allow probable component efficiencies to be deduced. The potential performance of a turboprop engine based on using the micro-gas turbine as a core was calculated assuming the same component efficiencies. Specific fuel consumption was found to be five times that of modern helicopter engines. Te recuperative cycle was examined and advantages for small-scale engines were confirmed. A proposal was written to develop a performance code for recuperative engines to allow design studies for UAV missions.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: UAV propulsion, small gas turbine engines, micro-gas turbines

STRUCTURAL DYNAMIC ANALYSIS OF THE RAH-66 "COMANCHE" HELICOPTER

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Aviation and Troop Command

OBJECTIVE: Professors Wood, Danielson and Gordis will continue their work in support of the ongoing development of the Army's RAH-66 *Comanche* helicopter. Tasks include vibration and structural dynamics analysis, and include correlation of calculated results with results of ground vibration tests. It is important that NPS maintain a "current" dynamic NASTRAN model of the *Comanche.* A current model permits NPS to respond quickly to requests

from the Program Manager's Office to carry out parametric investigations of RAH-66 vibrations in cooperation with the Army and Sikorsky in which NPS results can be quickly compared to those of other principals and applied to the aircraft if desired.

SUMMARY: During the current year Sikorsky's *correlated* NASTRAN model was provided to the NPS project. 'Correlated' refers to the fact that changes were made in both the stiffness and mass distribution of the initial or uncorrelated model to bring it into agreement with the actual vibration test measured data. During the past year this model was implemented at NPS. Modes shapes and frequencies were obtained up to 50 Hz. Forced response runs of the model were made under representative rotor loads at both 1/rev. and 5/rev. rotor excitation. Plots of the response of the structure were obtained for significant eigenvalue cases and all forced response cases. These results were presented to the Army as part of the NPS presentation given to the St. Louis Chapter.

NPS students also participated in the program. LT Bill Beaver joined the Sikorsky Dynamics Group under Bob Blackwell for a 1996 summer internship in which he worked on Comanche vibrations. LT John Harris conducted suspended vibration test of the OH-6A for his MSAE thesis. Vibration results agreed favorably with MDHC measured values. LT Mike Pampalon implemented a dynamic NASTRAN model of the OH-6A helicopter for his MSME thesis. His calculated frequency results agreed favorably with those obtained by McDonnell Douglas.

THESIS DIRECTED:

Beaver, W.F., "Determination of Hub Moments and Forces on the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, December, 1996.

Harris, John H., "Preliminary Vibration Survey of a Suspended Full-Scale OH-6A Helicopter from 0 to 45 Hz," Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Materials, Processes and Structures, Manufacturing Science and Technology, Modeling and Simulation.

KEY WORDS: Helicopter, rotorcraft, dynamics, structures

A MULTIDISCIPLINARY ASSESSMENT OF THE CHANGING ROLE OF ROTORCRAFT IN JOINT WARFARE

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School-Institute of Joint Warfare Analysis

OBJECTIVE: Rotorcraft play a key role in the joint warfare arena with their unique capabilities which include Anti-submarine Warfare (ASW), reconnaissance, Special Operations, and anti-tank warfare. This is a program directed at coordinating the activities of the NPS Vertical Flight Technology Center with the Institute of Joint Warfare Analysis. Under this activity a school-wide interdisciplinary program is developed in which Special Operations rotorcraft technology needs are identified, the needs are broken out and then allocated to relevant NPS activities for implementation.

SUMMARY: A number of technical problem areas were identified that relatee of helicopters in Special Operations. Some solutions were developed as well. Among those participating were Mr. Rhett Flater, Executive Director of the American Helicopter Society, U.S. Army Capt. Neil Thurgood, a helicopter pilot assigned to the 160th Special Operations Regiment, Professors Wayne Hughes, Joshua Gordis, and Don Danielson of NPS.

Central to rotary wing special operations is stealth. As a result helicopters fly at night, under the most adverse weather conditions, and take advantage of all possible means to avoid detection. Flight is generally carried out in nap-of-the-earth conditions, including flight up canyons and in relatively densely wooded areas. Tools of the trade include FLIR, Night Vision Goggles, and more recently aircraft-installed PNVS. The NOTAR® anti-torque system developed

by McDonnell Douglas reduces the tail rotor noise signature of the helicopter and is much better suited to flight through wooded areas. For these and other reasons, it has seen wide use on the smaller Special Operations helicopters.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Computing and Software, Electronic Warfare,Human Systems Interface, Materials, Processes and Structures, Manufacturing Science and Technology, Modeling and Simulation

KEY WORDS: Helicopters, stealth, rotary wing, special operations warfare, joint warfare modeling and simulation

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IN-SITU MEASUREMENT OF TOTAL DOSE RADIATION EFFECTS ON PARALLEL PLATE MOS CAPACITORS USING THE NPS LINEAR ACCELERATOR

Stuart M. Abrahamson-Lieutenant, United States Navy
B.S., Northwestern University, 1987
Master of Science in Electrical Engineering-December 1995
Master of Science in Astronautical Engineering-December 1995
Advisors: Sherif Michael, Department of Electrical and Computer Engineering
Oscar Biblarz, Department of Aeronautics and Astronautics

The study of radiation effects to electronics circuits has been ongoing almost as long as there have been satellites and spacecraft in space. The response to radiation over the planned life of the space system is of great concern to system designers. Operational amplifiers are one of the most basic elements in all electronic systems. This research examines radiation effects of part of a Metal Oxide Semiconductor (MOS) operational amplifier and is applicable to Complimentary MOS (CMOS) technology as well. More specifically, it is pertinent to MOS capacitors used to internally compensate op amps. First a review of semiconductor theory is presented followed by a discussion of damage mechanisms to MOS capacitors and a brief look at operational amplifier fundamentals. MOS capacitors, constructed by previous research efforts using the MOSIS technique, were selected as the internally compensating elements for simple low pass filters. Using the Naval Postgraduate School linear accelerator, these capacitors were irradiated with pulsed electrons possessing energies of up to 26 MeV for varying times. In-situ measurements were taken to immediately determine the capacitance value via the measured filter break frequency as a function of fluence. Separate irradiation runs were performed on three MOSIS capacitors and were terminated upon filter failure. This research concludes with a hypothesis of the filter failure mechanism and suggested areas for expansion of continuing research efforts. This is believed to be the first time such an experiment has been performed.

STARTUP CONTROL OF THE TOPAZ-II SPACE NUCLEAR REACTOR

Cal Dave Astrin-Lieutenant, United States Navy
B.S., University of New Mexico, 1989
Master of Science in Astronautical Engineering-September 1996
Advisor: Oscar Biblarz, Department of Aeronautics and Astronautics
Second Reader: Isaac Kaminer, Department of Aeronautics and Astronautics

The Russian designed and manufactured TOPAZ-II Thermionic Nuclear Space Reactor has been supplied to the Ballistic Missile Defense Organization for study as part of the TOPAZ International Program. A Preliminary Nuclear Safety Assessment investigated the readiness to use the TOPAZ-II in support of a Nuclear Electric Propulsion Space Test Mission (NEPSTP). Among the anticipated system modifications required for launching the TOPAZ-II system within safety goals is for a U.S. designed Automatic Control System. The requirements and desired features of such a control system are developed based upon U.S. safety standards. System theory and design are presented in order to establish the basis for development of a hybrid control model from available simulations. The model is verified and then used in exploration of various control schemes and casualty analysis, providing groundwork for future Automatic Control System design.

DEVELOPMENT OF A SURVIVABILITY AND LETHALITY ASSESSMENT CENTER (SLAC) AT NPS

Gary G. Bishop-Lieutenant, United States Navy
B.S., Rensselaer Polytechnic Institute, 1989
Master of Science in Applied Physics-September 1996
Advisors: Robert E. Ball, Department of Aeronautics and Astronautics
Gordon E. Schacher, Department of Physics

The purpose of this thesis is to develop a Survivability and Lethality Assessment Center (SLAC) at the Naval Postgraduate School. Students, faculty, and staff from many different curricula can use the SLAC for thesis research, for

validating their own computer codes, and for classroom instruction. The models for the SLAC were obtained from the Survivability/Vulnerability Information Analysis Center (SURVIAC), Teledyne Brown Engineering, Menton, Inc. (for Grumman A/C Systems Advanced Programs), and from the Physics Department at the Naval Postgraduate School. Computer Systems in the SLAC include two SUN SPARC-10 Workstations, one Silicon Graphics Indigo, eight VAX6310 terminals with four graphics display consoles, eight IBM compatible computers, and two Macintosh computers. The SLAC now contains 24 models for running simulations. The SLAC is a comprehensive, user-friendly center for individuals or groups that need to use it. The security processing, computer account set-up, and documentation have all been streamlined to facilitate ease of use. Students, faculty, and staff should have no difficulty utilizing the SLAC.

MEASURING THE EFFECTIVENESS OF WEAPONS SYSTEMS IN TERMS OF SYSTEM ATTRIBUTES

Kevin W. Brown-Captain, United States Marine Corps
B.S., The University of Virginia, 1988
Master of Science in Management-December 1995
Advisor: Robert E. Ball, Department of Aeronautics and Astronautics

In this thesis, the relationship between the characteristics or attributes of a military weapon system (e.g., speed, reliability, survivability) and the effectiveness of that system is thoroughly examined. Success in system acquisition relies on (1) the early identification and successful incorporation of those system attributes that are critical to system effectiveness, and (2) the specification of numerical values for the system attributes (the system requirements) that maximizes system effectiveness at an acceptable cost. New definitions for system, system attributes, and system effectiveness, as well as relevant DoDI 5000.2 guidance are provided. In addition to the currently-mandated battle level at which system effectiveness should be measured (in terms of engagement or battle outcomes), the author uses a wide spectrum of system acquisition-related literature to advocate that system effectiveness should also be measured at the mission level (in terms of mission outcome). Several existing mathematical models which combine a few key system attribute measurements into single-number measures of system effectiveness in accomplishing a particular mission are described. Then, the author proposes a hierarchy or tree which relates many system attributes to the four key attributes, Availability, Reliability, Survivability, and Capability, and hence to system effectiveness in accomplishing a specified mission.

APPLICATION OF MULTI-BLOCK CFD TECHNIQUES TO A MISSILE GEOMETRY

Bret S. Barton-Captain, Canadian Armed Forces
B.Eng., Technical University of Nova Scotia, 1989
Master of Science in Aeronautical Engineering-December 1995
Advisor: Garth Hobson, Department of Aeronautics and Astronautics

The aerodynamics of a missile body were modeled using computational fluid dynamics (CFD) techniques. A multi-block approach was used on a slender body and intersecting symmetric thin delta-wing. The CFD process and software were examined thoroughly including multi-block grid generation and interpolation, iblanking methods and flow-solver analysis. CFD results were compared with available wind tunnel data. Two Cartesian free-stream grids, a wing C-grid, a collar and body grid were used to model the body/wing geometry. The wing grid had a sharp tip and sharp leading and trailing edges. The body/wing intersection was represented with the collar grid. Both a hyperbolic grid generator, HYPGEN and an elliptic grid generator, GRIDGEN Vr 9, were evaluated. PEGSUS Vr 4.0 was used to compute the iblanking and interpolation stencil, based on the Chimera overlapping grid scheme. A single composite mesh was passed to the Navier-Stokes implicit flow-solver OVERFLOW Vr 1.6ag. Solutions were computed for inviscid and viscous flows at different Mach numbers and incidence angles. The Baldwin-Lomax shear and boundary layer turbulent models were used. Agreement was found between published wind tunnel data and the CFD solution thus validating the grid generation and flowfield solution procedure.

A HISTORICAL PERSPECTIVE OF AIRCREW SYSTEMS EFFECTS ON AIRCRAFT DESIGN

David O. Bauer-Lieutenant Commander, United States Navy
B.S., University of Kansas, 1981
Master of Science in Aeronautical Engineering-September 1996
Advisor: Conrad F. Newberry, Department of Aeronautics and Astronautics
Second Reader: Anthony P. Ciavarelli, School of Aviation Safety

The design of the aircrew workstation often has not been an orderly part of the overall aircraft design process but rather of much lower priority than the integration of the airframe and powerplant. However, the true test of the aircraft is how well the aircrew can use the aircraft for mission performance. NAVAIR has been seeking the establishment of an Aircrew Centered System Design discipline, to be addressed as an integral part of the global aircraft system design process. A baseline, historical understanding of how the aircrew have been integrated into the aircraft and mission is needed. An analysis was conducted of several significant airplanes from the Wright Flyer to the present, seeking those design factors which affected how well the aircrew were able to perform the design mission. The physical and attentional resources of the aircrew must be understood and accommodated by those designing the cockpit and other workstations. Aircrew members who are knowledgeable of, and experienced in the intended mission must be involved in the design process from the very earliest phases of concept definition.

MACSAP 3.0: SURVIVABILITY ASSESSMENT SOFTWARE FOR AIRCRAFT CONCEPTUAL DESIGN

Gary G. Bishop-Lieutenant, United States Navy
B.S., Rensselaer Polytechnic Institute, 1989
Master of Science in Aeronautical Engineering-June 1996
Advisor: Robert E. Ball, Department of Aeronautics and Astronautics
Second Reader: Conrad F. Newberry, Department of Aeronautics and Astronautics

The purpose of this thesis is to further develop the Macintosh Survivability Assessment Program (MACSAP) that was originally written in the multi-media programming language SuperCard® in September 1991. The program is designed to be autonomous and may be included in the second edition of The Fundamentals of Aircraft Combat Survivability Analysis and Design, by Robert E. Ball. The computer code is a training aid for the conceptual survivability design of three different combat aircraft: a long range strike aircraft, a close air support aircraft, and a fighter escort aircraft. MACSAP 3.0 modifies version 2.0 by improving on the design of the computer code. By writing more efficient code, the program runs 32% faster and has decreased in file size by 39%, so it can be contained on one 3.5 inch computer diskette. Additional improvements include the use of color coding to aid the student in using the software and supplementary graphics/screens with detailed descriptions of analysis procedures. MACSAP 3.0 is now a stand-alone, user-friendly computer program ready for the classroom.

FINAL MODIFICATIONS OF NPS *HUMMINGBIRD* REMOTELY PILOTED HELICOPTER IN PREPARATION FOR FLIGHT

Andrew J. Booth-Lieutenant, United States Navy
BME, Georgia Institute of Technology, 1988
Master of Science in Aeronautical Engineering-December 1995
Advisor: E. Roberts Wood, Department of Aeronautics and Astronautics

The goals of this thesis were to make final design modifications and perform static testing to prepare the *Hummingbird,* a 150 pound, remotely piloted helicopter (RPH), for untethered flight. The major elements involved were: (1) The adaptation of a suitable, permanently-dedicated test stand for use with large-scale RPH/RPV (remotely piloted vehicle) aircraft, (2) The rotor drivetrain improvements to the helicopter to enable it to safely operate in the event of an in-flight engine failure, thus avoiding the potential loss of aircraft due to crash, (3) Complete break-in and testing of a replacement engine for a mechanically-seized first engine, and (4) The actual flight testing while secured to the test stand.

The test stand modifications included the design and implementation of a compression spring to offset the weight of the newly designed mounting assembly and a restricting collar to confine the mobility of the stand's universal joint. The mechanical change to the drivetrain consisted of replacement of a conventional belt-driving sprocket with a one-way bearing inside the gear. This provides the *Hummingbird* with the critical capability to autorotate. The new engine, correctly broken in, and the subsequent static testing provide the Department of Aeronautics and Astronautics with a platform fully operational and ready to perform subsequent in-flight testing.

COMPUTATIONAL INVESTIGATION OF LOW SPEED FLOW OVER LOW ASPECT RATIO AIRCRAFT CONFIGURATIONS

Alain Carrier-Captain, Canadian Armed Forces
B.S., Ecole Polytechnique, University of Montreal, 1988
Master of Science in Aeronautical Engineering-December 1995
Advisor: Max F. Platzer, Department of Aeronautics and Astronautics

The objective of this thesis was to contribute to the development of a second-order approximation to the steady and oscillatory lifting flow past low aspect ratio wings by establishing the validity of a NASA-Ames developed incompressible three-dimensional flow panel code named PMARC, which would subsequently be used to test the range of validity of this second-order theory. The steady state configurations modeled in the validation process include swept back, delta and rectangular wings, an F5 wing and three equivalent bodies of revolution. Oscillatory cases were also run with one delta and the F5 wings and their respective equivalent bodies of revolution, as well as with one spindle. In steady state, comparison with experimental and theoretical data proved PMARC to be very accurate for lift and pressure calculations, but revealed a discrepancy in the velocity distribution calculation around delta wings. This finding was corroborated by applying the slender body/slender wing theory (Oswatitsch-Keune theory) to the delta wing. The unsteady state results are presented, but their validation is left for future work. As part of its primary objective, this thesis also presents a computer code that generates the F5 wing equivalent body of revolution from its chord-wise section definition. In order to be used as base software to the second-order theory, PMARC will have to be corrected, or a new software will have to be validated.

A STUDY ON THE EFFECTS OF THROTTLE CHANGES AND FLARE DECOYS IN AN ENGAGEMENT BETWEEN THE F-14B/D TOMCAT AND THE AA-11 ARCHER IR AAM

Ramon A. Collazo, Jr.,-Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1984
Master of Science in Aeronautical Engineering-March 1996
Advisors: R. Ball, Department of Aeronautics and Astronautics
F. Levien, Information Warfare Academic Group

Technological advances coupled with extensive proliferation of infrared (IR) guided Surface-to-Air (SAM) and Air-to-Air (AAM) missiles arguably make them the most dangerous threat faced by tactical aircrews. The U. S. Navy has addressed this threat through aggressive IR countermeasures (IRCM) programs. One such program is the Electronic Warfare Advanced Technology (EWAT) Program sponsored by the CNO (N88). The Naval Postgraduate School and the EWAT Program are working together using modeling and simulation programs to evaluate proposed IRCMs.

This thesis uses the Modeling System for Advanced Investigation of Countermeasures (MOSAIC) software to simulate engagements between the Soviet-made AA-11 Archer IR AAM and the F-14B/D. Two scenarios, preemptive and defensive, are explored in which the F-14 uses flare decoys and/or reduction in power setting as recommended by the Navy Fighter Weapons School in an attempt to defeat the missile. A power modulation tactic, proposed by the Naval Air Warfare Center, Weapons Division, China Lake, is also examined. The results of the simulations are evaluated to determine the effectiveness of both current and proposed IRCM tactics.

POWER PLANT AND DRIVE TRAIN IMPROVEMENTS OF THE NPS *HUMMINGBIRD* REMOTELY PILOTED HELICOPTER

Robert E. Conway-Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1985
Master of Science in Aeronautical Engineering-September 1996
Advisor: E. Roberts Wood, Department of Aeronautics and Astronautics
Second Reader: Richard M. Howard, Department of Aeronautics and Astronautics

Originally designed as a target drone for the U.S. Army, the NPS Hummingbird has undergone several modifications to convert it into a reliable research platform. The 165 pound remotely piloted helicopter (RPH) is powered by a Weslake Aeromarine Engines Limited (WAEL) 342 two stroke, twin cylinder, 25 hp, gasoline engine. An engine failure due to cylinder overheating halted research efforts until investigation as to the cause and subsequent corrections could be made. Costing approximately $3000 per engine, another failure is unacceptable. The tasks undertaken in this thesis were to investigate the cause of the overheat failure and improve the engine cooling system. Cooling system corrections required total redesigns of the engine cooling and engine start systems. Additionally, research of the RPH's history revealed a need for a torsional shock absorber to be incorporated in the drive train to increase component life. The changes made to Hummingbird provide a decrease in empty weight, minimal center of gravity change and, most importantly, an increase in user safety, providing the Department of Aeronautics and Astronautics with a dependable vehicle for rotary wing research.

EXPERIMENTAL ANALYSIS OF THE WAKE OF AN OSCILLATING AIRFOIL

Claus M. Dohring-Commander, German Navy
Dipl. Ing., Universität der Bundeswehr München, 1981
Master of Science in Astronautical Engineering-June 1996
Advisor M.F. Platzer, Department of Aeronautics and Astronautics
Second Reader: M.S. Chandrasekhara, Department of Aeronautics and Astronautics

The wake of an airfoil that oscillates in pure plunge mode is investigated in a water tunnel over a wide range of reduced frequency and amplitude. The main focus of this study is the comparison of the experimentally determined wake geometry with numerical results from a potential flow code. The wake vortices are visualized by two-color dye injection and velocity profiles are measured with LDV upstream and downstream of the airfoil. Wake signatures are examined with regard to thrust or drag generation. There is a good agreement between calculated and experimental data of the vortical wavelength. At high plunge velocities both approaches show a loss of wake symmetry and the emergence of a dual mode wake behavior.

A VALIDATION OF THE JOINT ARMY/NAVY ROTORCRAFT ANALYSIS AND DESIGN SOFTWARE BY COMPARISON WITH H-34 AND UH-60A FLIGHT TEST

David M. Eccles-Lieutenant, United States Navy
B.S.E.E., Tufts University, 1987
Master of Science in Aeronautical Engineering-December 1995
Advisor: E. Roberts Wood, Department of Aeronautics and Astronautics

A detailed comparison of the output from the NPS developed Joint Army/Navy Rotorcraft Analysis and Design (JANRAD) computer code with H-34 and UH-60A flight test data was made in an effort to determine the validity of the code's predictions. Airload distribution across the rotor disk, power required at various airspeeds ranging from hover to cruise, and thrust moment were used as measures of performance. Although a quantitative comparison of airload distribution is difficult to obtain, qualitatively, the predictions are good. JANRAD's power required estimations are correct to within two percent for altitudes below six thousand feet but accuracy suffers at higher altitudes, particularly above ten thousand feet. A correlation between the variation in kinematic viscosity from sea level to ten thousand feet and the accuracy of the power predictions is demonstrated. In the case of the UH-60A, the equivalent flat plate area of

the helicopter is shown to be a function of airspeed, significantly impacting the accuracy of the power required prediction. Center of gravity offset from the main rotor's axis of rotation and unsteady inflow effects influence the accuracy of thrust moment predictions.

OPTIMIZATION AND PERFORMANCE ANALYSIS OF WAVERIDER CONFIGURED INTERPLANETARY SPACE VEHICLES

John M. Flynn-Lieutenant, United States Navy
B.S., University of Southern California, 1989
Master of Science in Astronautical Engineering-June 1996
Advisor: Conrad F. Newberry, Department of Astronautics and Aeronautics
Second Reader: Jeffrey V. Bowles, NASA Ames Research Center

This thesis describes a number of issues associated with waverider configured spacecraft designed for interplanetary missions. The first such issue is the determination of the magnitude of the energies and velocities required for conventional gravity-assist (GA) spaceflight maneuvers contrasted with energies and velocities required for less conventional aero-gravity assisted (AGA) maneuvers for interplanetary spaceflight travel. These comparisons will be made for an Earth-Mars shuttle mission, a mission to Saturn, a mission to Neptune, and a round-trip mission to Saturn. Two additional issues considered for each mission are the fuel requirements and flight time parameters for both gravity-assist and AGA maneuvering spaceflight trajectories. This research includes the use of the patched conic interplanetary trajectory optimization MIDAS (Mission Design and Analysis Software) code for mission flight path analysis developed by the Jet Propulsion Laboratory. Waverider configuration development and off-design aerothermal analysis for each mission was supported by the NASA Ames Research Center's Waverider code (a subset of the Hypersonic Aircraft Vehicle Optimization Code) and a modified AEROSA code employing a Martian atmosphere, respectively. The results of this research showed that by using AGA, launch windows could be widened, flight times could be reduced by 25%, and fuels could be reduced by 30%.

CONCEPTUAL DESIGN DEFINITION OF A JSOW UNITARY CATM

Gary Lee Formet, Jr.-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Aeronautical Engineering-June 1996
Advisor: Gerald H. Lindsey, Department of Aeronautics and Astronautics
Second Reader: Sandra L. Scrivener, Department of Aeronautics and Astronautics

The AGM-154 Joint Stand Off Weapon (JSOW) Unitary missile is the next generation of smart weapons. This document seeks to provide insight into needed capabilities for the Captive Air Training Missile (CATM) which simulates the AGM-154 JSOW Unitary variant. This is done by presenting a proposed training program within the framework of aircraft carrier operations that justifies and delineates the CATM. From these, insights into the engineering conceptual design goals that will apply to the CATM are extracted. Required capabilities and functions from these operations are discussed, which ultimately leads to the foundation for a draft Functional Requirements document and a revised Concept of Operations document for the CATM.

A WATER TUNNEL INVESTIGATION OF THE INFLUENCE OF REYNOLDS NUMBER ON THE HIGH-INCIDENCE FLOW OVER DOUBLE-DELTA WINGS

Anastasios E. Fritzelas-Lieutenant, Hellenic Navy
B.S., Hellenic Naval Academy, 1986
Master of Science in Aeronautical Engineering-March 1996
Advisor: M.F. Platzer, Department of Aeronautics and Astronautics

There are several disagreements in the published literature on vortex interaction and bursting data obtained in various wind and water tunnel tests of double-delta wings at high angle of attack (AOA).Therefore a test program was carried out in the Naval Postgraduate School water tunnel using a 76/40 deg. baseline double-delta wing model to investigate the effect of Reynolds number. The program consisted of: (i) Flow visualization studies at tunnel speeds of 0.2, 0.6 and 1.0 ft/sec in the 0-30 deg. AOA range to determine the influence of flow Reynolds number on vortex trajectory/ interaction and breakdown, and (ii) Laser Doppler Velocimetry studies of the flowfield to gain a better understanding of the vortex structure and verify the flow visualization results. Comparison of the test results at these tunnel speeds (corresponding to nominal flow Reynolds number of 15,000, 45,000, and 75,000) indicates a change in the vortical flowfield structure. The strake and wing vortices do not coil up and the breakdown occurs earlier as the tunnel speed is increased. The trends in the interaction and bursting data at higher tunnel speeds appear to be in better agreement with previous wind tunnel data.

NEURAL PREDICTION OF MISSILE DYNAMICS DURING HARDWARE-IN-THE-LOOP CAPTIVE-CARRY EXPERIMENTS

Charles W. Gill-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Aeronautical Engineering-September 1996
Advisor: Phillip E. Pace, Department of Electrical and Computer Engineering
Second Reader: Robert E. Ball, Department of Aeronautics and Astronautics

Systems using electronic attack (EA) are needed to defeat enemy active threat missiles. Many such systems exist, but difficulties arise when trying to measure their effectiveness. Two methods used are closed loop tests in an anechoic chamber and open loop tests conducted with a hardware-in-the-loop (HIL) threat simulator on board an aircraft. This thesis investigates the feasibility of using a particular class of neural networks (Levenburg-Marquardt) to predict the dynamics of an anti-ship cruise missile (ASCM) using only the seeker measured range-to-target and antenna azimuth and elevation angles. This technique accounts for seeker measured range and angles having a nonlinear relationship with the missile flight dynamics. Closed loop anechoic chamber simulations provide missile dynamics in an artificial environment while open loop captive-carry flight tests provide a true EA environment, but no dynamics. Closed loop and open loop results are combined to assess the effectiveness of the EA used by the Navy to defeat enemy missiles. The neural networks are trained using missile dynamics from closed loop simulations and are used to provide missile dynamics for open loop simulations. As an integral part of captive-carry signal processing tools, the prediction of the ASCM dynamics using neural networks considerably improves miss distance calculations.

ANNULAR TURBINE CASCADE UTILIZING A PRESSURIZED AERODYNAMIC WINDOW

Michael Hiro Guerrera-Lieutenant, United States Navy
B. S., United States Naval Academy, 1988
Master of Science in Aeronautical Engineering-September 1996
Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics
Second Reader: Raymond P. Shreeve, Department of Aeronautics and Astronautics

The purpose of this research was to compare previous laser-anemometry measurements obtained through an unpressurized laser window with the results from a pressurized laser window and to validate this innovative measuring technique in the endwall region of a confined annulus. Two-dimensional velocity, flow angle, and turbulence intensity measure-

ments were obtained with a fiber-optics laser-Doppler velocimeter. The measurements were performed through a 1.09 mm opening in the endwall region of an annular turbine cascade at depths ranging from 0.01 mm to 0.89 mm with varying pressure applied to the chamber of the modified window. Cobra probe measurements were performed to validate the flow angles obtained by the laser anemometer. The cascade was modified to measure the inlet profile, which was performed with a three-hole probe.

CONVECTIVE HEAT TRANSFER FROM A CYLINDER IN A STRONG ACOUSTIC FIELD

Donald Ray Harder-Lieutenant, United States Navy
B.S., University of Washington, 1989
Master of Science in Mechanical Engineering-December 1995
Master of Science in Astronautical Engineering-December 1995
Advisors: Ashok Gopinath, Department of Mechanical Engineering
Oscar Biblarz, Department of Aeronautics and Astronautics

Experimental work was performed to study the convective heat transfer characteristics from a cylinder in a strong zero-mean oscillatory flow represented by an acoustic field. Two different flow regimes are discussed; that in which laminar, attached flow around the cylinder is present, and that in which instabilities, such as vortex shedding occur. The experiment utilizes a steady state measurement method. A transition from the laminar to the unstable regime was observed to occur at a streaming Reynolds number of approximately 240. Within the laminar regime, the transition from "intermediate" to "large" values of the streaming Reynolds number occurs at approximately 130. Heat transfer results for large values of the streaming Reynolds number in the laminar regime closely match the present theory (less than 13% error). Correlations were developed to relate the heat transfer rate to the streaming Reynolds number in the unstable regime. This work would find application in the design of heat exchangers for a thermoacoustic engine.

EXPERIMENTAL VERIFICATION OF AN OPTIMAL LINEAR CONTROLLER FOR A FLEXIBLE STRUCTURE

William Burke Harrington, Jr.-Lieutenant Commander, United States Navy
B.S., Marine Engineering, United States Naval Academy, 1985
Aeronautical and Astronautical Engineer-December 1995
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics

Nanometer accuracy in many space applications requires that sensors be isolated from vibration disturbances by the main spacecraft body. The Flexible Spacecraft Simulator (FSS) at the Naval Postgraduate School is designed for testing multiple control system designs. The experimental setup simulates a microgravity environment for a flexible Structure. A twenty-four state finite element model is used to characterize the flexible appendage. Piezoelectric ceramic wafers bonded to the structure are the actuators and sensors. A VisionServer external infrared camera provides direct feedback of the flexible structure's elbow and tip displacements to sub-millimeter accuracy. A Multiple-Input-Multiple-Output (MIMO) Linear Quadratic Gaussian (LQG) controller is experimentally compared with a Positive Position Feedback/Velocity feedback controller. The damping is increased on the order of 825% for both control implementations. The objective is to minimize the disturbance of the tip of the flexible structure, representing the reflector support point.

PRELIMINARY VIBRATION SURVEY OF A SUSPENDED FULL-SCALE 0H-6A HELICOPTER FROM O TO 45 HZ

John H. Harris III-Lieutenant, United States Navy
B. S., The Pennsylvania State University, 1988
Master of Science in Aeronautical Engineering-March 1996
Advisor: E. Roberts Wood, Department of Aeronautics and Astronautics
Joshua H. Gordis, Department of Mechanical Engineering

Efforts to establish a helicopter research program in structural dynamics at NPS were greatly enhanced when the U. S. Army donated two OH-6A light observation helicopters. One of the helicopters is reserved for ground vibration testing and dynamics research. Vibration measurements are extremely important in predicting and understanding an aircraft's dynamic behavior and durability. A comparison of a helicopter's natural frequencies and those frequencies transmitted to the airframe through the rotor system can alert the designer/evaluator to possible dynamic problems. This thesis establishes a baseline vibration test program on the OH-6A helicopter for future testing and comparison to analytic models. The goal of the research is to establish natural frequencies (eigenvalues), principal mode shapes (eigenvectors), and damping characteristics of the OH-6A and to compare these values to test and analytical data obtained from the McDonnell Douglas Helicopter Company.

AN ANALYSIS OF COMMERCIAL LOW EARTH ORBIT AND MEDIUM EARTH ORBIT MOBILE SATELLITE SYSTEMS AND THEIR POTENTIAL FOR MILITARY USE

Dana L. Haskell-Major, United States Marine Corps
B.S., University of Maine at Orono, 1984
Master of Science in Systems Technology (Space Systems Operations)-September 1996
Advisor: Brij Agrawal, Department of Aeronautics and Astronautics
Second Reader: Dan C. Boger, Command, Control, and Communications Academic Group

In recent years the United States military has been employed in more and more non-traditional roles as well as maintaining the ability to respond to crises throughout the entire spectrum of conflict. These missions can range from assisting civilian authorities providing disaster relief to responding to a major regional contingency. Often times these operations take place in remote or war torn regions of the world with little or no communications infrastructure. Additionally, today's emphasis on rapid deployment and maneuver warfare has resulted in our surpassing the capabilities of current military communications equipment. Expensive military satellite programs as well as the decline in defense spending has shifted our focus to more cost effective means of satisfying these requirements. Commercial mobile satellite systems (MSSs) such as Motorola's Iridium, Loral/Qualcomm's Globalstar, and TRW's Odyssey offer a possible solution. This thesis analyzes these three commercial MSSs, expected to have initial operational capabilities before the turn of the century, and their ability to satisfy current and anticipated DoD operational requirements. Each of these systems is examined in terms of their capabilities, vulnerabilities, and cost. Based on this analysis, a determination is made as to their potential for military use.

RADIATION PATTERN CALCULATION FOR MISSILE RADOMES IN THE NEAR FIELD OF AN ANTENNA

Scott M. Herzog-Lieutenant, United States Navy
B.S.A.A.E, The Ohio State University, 1988
Master of Science in Aeronautical Engineering-September 1996
Advisor: David C. Jenn, Department of Electrical and Computer Engineering
Second Reader: Robert E. Ball, Department of Aeronautics and Astronautics

An analytical model and computer simulation are presented for a radome located in the near field of an antenna. Using the computer code described here, design tradeoffs can be performed between electrical, structural, and aerodynamic properties of the radome. The code is based on a method of moments solution to the E-field integral equation for bodies

of arbitrary shape. Measured radiation patterns for AGM-88 High Speed Antiradiation Missile (HARM) and AIM-SIC missile radomes are compared to computed data.

DESIGN, DEVELOPMENT AND TESTING OF THE ALL-REFLECTION MICHELSON INTERFEROMETER FOR USE IN THE MID-ULTRAVIOLET REGION

Jeffrey D. Hicks-Lieutenant, United States Navy
B.S., Auburn University Auburn, Alabama, 1988
Master of Science in Astronautical Engineering-December, 1995
Master of Science in Applied Physics-December, 1995
Advisor: D.D. Cleary, Department of Physics Department

The development of the Naval Postgraduate School's high resolution All-Reflection Michelson Interferometer has progressed into the mid-ultraviolet region. Two separate Mercury light sources, a pen-ray lamp and a germicidal lamp, were used to evaluate the performance of the instrument for the 2537 Å emission. The interferometer uses a pinhole aperture at the focus of an off-axis parabolic mirror to obtain a collimated input beam. A plane sinusoidal diffraction grating divides the beam into two orders. Planar mirrors reflect the beams back to the grating where they are diffracted again such that both beams are now in the plane of the detector. The beams recombine to form a linear interference pattern which is recorded by an ultraviolet detector. Data-reduction software coherently adds the interference pattern matrix and creates a doubled-sided interferogram. The spectrum is obtained by using Fourier Transform techniques. This compact, lightweight and economically produced interferometer has no moving parts. For this reason, the All-Reflection Michelson Interferometer is well suited for remote sensing of mid- to extreme-ultraviolet ionospheric emissions from a sounding rocket, space shuttle or satellite platform.

A STUDY OF THE MEASURES OF EFFECTIVENESS FOR THE JMSDF AEGIS DESTROYER IN A LITTORAL, AIR DEFENSE ENVIRONMENT

Hideto Ito-Lieutenant Junior Grade, Japanese Maritime Self Defense Force
B.S., National Defense Academy Japan, 1990
Master of Science in Aeronautical Engineering-December 1995
Advisor: Robert E. Ball, Department of Aeronautics and Astronautics

Maritime operations in a littoral area demand a fundamental change in the future defense build-up of the Japanese Maritime Self Defense Force (JMSDF). The anti-air warfare (AAW) capability of the JMSDF in the littoral area, especially against very low altitude anti-ship cruise missiles (ASCMs), should be improved. To achieve the required future air defense lethality, the JMSDF must optimize the resource allocation within a limited budget. Therefore, it is important to understand the essential elements of air defense lethality by the JMSDF Aegis destroyer in order to improve their operational effectiveness. In this study, a measure of effectiveness (MOE) for Aegis lethality against an ASCM attack is defined as "a denial area at an acceptable risk." Using this MOE, spread sheet lethality models based on Aegis weapons characteristics, target detection range, reaction time, and ASCM speed, are developed and used to study several alternative improvements to Aegis.

AAW EFFECTIVENESS OF THE DD-963 SPRUANCE CLASS DESTROYER: AN ANALYTIC MODEL

Richard O. Johns-Lieutenant, United States Navy
B.E.E., Villanova University, 1988
Master of Science in Operations Research-September 1996
Advisor: W. Max Woods, Department of Operations Research
Second Reader: Robert E. Ball, Department of Aeronautics and Astronautics

A typical naval ship has multiple systems which can be used to defend itself against a cruise missile threat. These systems may consist of surface-to-air missiles, MK 45 guns and the Close-in-Weapon-System to name a few. Until recently each of these system's effectiveness against a cruise missile was assessed independently of the other systems onboard the ship. The purpose of this thesis is to develop an overall system effectiveness model for the DD-963 Spruance class destroyer. The model considers the integration of the defensive systems onboard, the availability and reliability of these systems and contains parameters that can be used to incorporate the crew's ability to employ the various weapon systems against a cruise missile threat.

DESIGN AND IMPLEMENTATION OF A GEOLOCATION SOFTWARE WORKBENCH

Gregory Ian Jones-Lieutenant, United States Navy
B.A., University of Florida, 1988
Master of Science in Engineering Science-March 1996
Advisors: Herschel H. Loomis, Jr., Department of Electrical and Computer Engineering
Sandra Lynn Scrivener, Department of Aeronautics and Astronautics

This thesis explores the background and concerns involved in creating a multipurpose software tool that can be used to process electronic signals in an effort to determine the signal's point of origin. A functional workbench utilizing stand-alone software modules was constructed using the MATLAB® software environment. Specific emphasis was placed upon the following aspects: determining the formats for, and actually coding, input and output data file interfaces, propagation path error accounting, geolocation algorithm implementation, arid graphical user interface design. A well-known geolocation method, Time Difference of Arrival (TDOA), was chosen to be the Geolocation Workbench's first example. The result of this effort is a working software model that demonstrates how this workbench can be used effectively by geolocation algorithm developers and geolocation end users alike.

A COST AND OPERATIONAL EFFECTIVENESS ANALYSIS FOR FUTURE ARTILLERY SYSTEM IN KOREA

Chunsoo Kang-Major, Republic of Korea Army
B.S., Korea Military Academy, 1985
Master of Science in Applied Physics-December 1995
Advisors: Robert E. Ball, Department of Aeronautics and Astronautics
William B. Colson, Department of Physics

The goal of the defense acquisition program is finding the most effective system with the least cost. There are two key functions to achieve this goal: measuring the effectiveness and estimating the cost of each alternative. However, the acquisition procedure of a new weapon system is very complex and uncertain, because it involves anticipating the advantages and disadvantages both friendly and adversaries currently and/or in the future. Also estimating the Life Cycle Cost requires time and huge amount of data. The U.S. Department of Defense Instruction 5000 series was prepared to show how to avoid these complexities and uncertainties, known as a Cost and Operational Effectiveness Analysis (COEA).

The main purpose of this study is to show the COEA procedures and format by following the procedures specified in U.S. DoD Instruction 5000 series with an example of the future artillery system in Korea. As background, the concepts and terminologies of COEA and field artillery fire support are briefly examined. Following the format and

procedures, the focus of this study is on the measures of the operational effectiveness of the field artillery system by using the computer simulation. The result of the simulation with different scenarios quantifies the performance characteristics and shows the relative effectiveness of each alternative.

The other parts are also explained briefly. The acquisition issues partly covers the inferiority of military balance between South and North Korea, and estimating costs for each alternative analyzed with a short example because of the lack of data and time limit. This thesis concludes with a summary of the results so that it discriminates and ranks each alternative.

LOW-SPEED WATER TUNNEL FLOWFIELD VISUALIZATION STUDIES OF THE HYPERSONIC LOFTY WAVERIDER CONFIGURATION

Andrew M. Kenny, Jr.-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Aeronautical Engineering-September 1996
Advisor: C.F. Newberry, Department of Aeronautics and Astronautics
Second Reader: S.K. Hebbar, Department of Aeronautics and Astronautics

A flow visualization study of the vortical flow over a scale model LoFLYTE waverider configuration was conducted in the Naval Postgraduate School water tunnel facility using a dye-injection technique. The main focus of this investigation was to analyze vortex development, vortex core trajectories, and vortex bursting phenomena at high angles of attack (AOA) with and without sideslip. Still photographs and video frames were taken for pitch angles between 18° and 40° and yaw angles between 0° and 10°. At pitch angles lower than 18°, the vortex cores were not well developed and barely discernible. The LoFLYTE waverider vortical flowfield resembled that of sharp leading edge delta wings with similar leading edge sweep. As AOA increased, the longitudinal burst location of the vortices moved forward toward the model apex. The lateral position of the vortex cores remained constant with increasing AOA. In a sideslip condition vortex asymmetry was present, but as AOA was increased the vortex asymmetry was reduced. The secondary aspect of this investigation analyzed the behavior of the flow on the bottom surface of the waverider model, particularly in the vicinity of the engine inlet. As AOA was increased from -2° to 18°, the dye streaklines on the bottom surface were eventually drawn to the top surface due to the strong suction created by the development of well defined vortices originating at the sharp leading edges.

LINEAR MODELING OF TILTROTOR AIRCRAFT (IN HELICOPTER AND AIRPLANE MODES) FOR STABILITY ANALYSIS AND PRELIMINARY DESIGN

Gary D. Klein-Captain, United States Marine Corps
B.S., Aerospace Engineering, United States Naval Academy, 1985
Master of Science in Electrical Engineering-June 1996
Master of Science in Aeronautical Engineering-June 1996
Advisors: Robert G. Hutchins, Department of Electrical and Computer Engineering
E. Roberts Wood, Department of Aeronautics and Astronautics

This thesis investigates the linear state space modeling of a tiltrotor aircraft by modifying an existing MATLAB routine which is used for preliminary (helicopter) stability and control analysis. The modifications consist of changing existing script files along with adding new ones. The modifications result in having a routine that allows the input of tiltrotor characteristics and subsequently generates a state space model along with other stability and control characteristics. The tiltrotor modeling is validated by the input of XV-15 characteristic data into the program and performing a eigenvalue comparison with a model of a similar tiltrotor, the V-22. A more extensive comparison is performed with another XV-15 model which has been extensively used and validated with wind tunnel and flight.

ORBITAL PERTURBATION ANALYSIS OF EARTH-CROSSING ASTEROIDS

Wade E. Knudson-Lieutenant Commander, United States Navy
B. S., United States Naval Academy, 1984
Aeronautical and Astronautical Engineer-December 1995
Advisor: I.M. Ross, Department of Aeronautics and Astronautics

Earth-Crossing Asteroids (ECAs) are those asteroids whose orbit cross-section can intersect the capture cross section of the Earth as a result of secular gravitational perturbations. This thesis provides a framework for understanding the origin, nature, and types of ECAs. The change in velocity requirements to achieve a two Earth radii deflection for long- and short-term warning scenarios are developed. Next, a method of developing hypothetical Earth colliding asteroid orbits is presented. These hypothetical orbits are used in two ways: (1) to evaluate the ability of Dance of The Planets, a solar system simulation model developed by Applied Research and Consulting, Inc., to accurately propagate orbits of imported asteroid orbits, and (2) to analyze the sensitivity of deflection distance to variation in deflection angle and orbital parameters of a given orbit. Inaccuracies during importation of data precluded the use of Dance of the Planets for the purpose of sensitivity analysis. The program does provide an excellent tool for visualization of ECA scenarios. Consequently, a simpler orbital model was developed to provide a Earth miss distance sensitivity analysis. With one asteroid orbital period warning the minimum change in velocity to deflect an asteroid two Earth radii is approximately 0.135 m/s and the optimal deflection is along the flight path. Maximum deflection occurs when the deflection is applied at perihelion. The miss distance decreases markedly with increase in true anomaly until it is a minimum at aphelion.

THE EFFECTS OF PARTICULATES ON SUPERSONIC SHEAR LAYERS AND AFTERBURNING IN FUEL-RICH PLUMES

Siwon Ray Lee-Lieutenant, United States Navy
B.S., Tulane University, 1983
Master of Science in Astronautical Engineering-December 1995
Advisor: David W. Netzer, Department of Aeronautics and Astronautics

An investigation was conducted to experimentally quantify the interaction of particulates with the fuel-rich plume flowfield typical for solid propellant rocket motors. This was done in order to optimize enhanced mixing devices or chemical-additive addition for afterburning suppression. Laser sheet flow visualization, sound spectra measurements, plume thermal images and particle size distribution measurements were utilized with reacting and non-reacting gaseous plumes and with the plumes from highly aluminized propellant and minimum smoke propellant. Several devices were evaluated for their effectiveness in providing increased mixing in the supersonic shear layer. It was found that the generation of axial vortices in the supersonic shear layers at the nozzle exit of rocket motors operating with characteristically high exit Mach numbers and high temperatures can enhance the mixing rates and affect the afterburning. The presence of large quantities of particulates both in the shear layer and in the plume core appears to significantly change the results obtained using enhanced mixing devices. Initial results with a ramp nozzle indicate that enhanced large-scale mixing can be provided in the presence of high particulate loadings in the plume.

EVALUATION OF THE BOEING PAN AIR TECHNOLOGIES CODE (A502I) THROUGH PREDICTION OF SEPARATION FORCES ON THE GBU-24

Matthew Alan LeTourneau-Lieutenant, United States Navy
B.S., The George Washington University, 1988
Master of Science in Aeronautical Engineering-March 1996
Advisor: Max F. Platzer, Department of Aeronautics and Astronautics

The Boeing PAN AIR Technologies code (A502i) is investigated to explore its suitability for determination of separation forces on ordnance. To this end, A502i is first assessed by applying it to three problems for which other solutions and experimental data are available, i.e., steady flow past a rectangular, parabolic arc wing and a delta wing at both

subsonic and supersonic conditions. Good agreement is found in all cases. A502i is then applied to the GBU-24's being in two configurations for a subsonic case and a supersonic case. Good agreement is found with data obtained from wind tunnel experiments for low angles of attack.

AUTONOMOUS CONTROL OF UNDERWATER VEHICLES AND LOCAL AREA MANEUVERING

David Bryan Marco-Civilian
B.S., Oklahoma State University, 1983
M.S. University of Texas at Austin, 1987
Doctor of Philosophy in Mechanical Engineering-September 1996
Advisors: Anthony J. Healey, Department of Mechanical Engineering
Robert Cristi, Department of Electrical and Computer Engineering
Robert B. McGhee, Department of Computer Science
Fotis A. Papoulias, Department of Mechanical Engineering
Louis V. Schmidt, Department of Aeronautics and Astronautics

The major thrust of this work is the development and demonstration of new capabilities for the use of small autonomous vehicles in mine countermeasure applications. Key to the new capabilities lies in an open architecture tri-level software structure for hybrid control, of which this work is the first validated implementation. The two upper levels run asynchronously in computing logical operations based on numerical decision making, while the lowest, the Execution Level, runs synchronously to maintain stability of vehicle motion. The top (Strategic) Level of control uses Prolog as a rule based language for the specification of the discrete event system (DES) aspects of the mission. Multiple servo controllers are coordinated by the middle (Tactical) Level software in performing the mission, while the Execution Level controllers guarantee robust motion stability through multiple sliding modes.

This hardware/software arrangement provides the ability to operate a hybrid (mixed discrete state/continuous state) controller for semi-autonomous and autonomous vehicles in which the missions imply multiple task robot behavior. This work has defined and developed a set of vehicle "primitives", that are a set of stable modular control functions unique to a given vehicle's capabilities. It is demonstrated how these can easily be combined using rules to specify as simple, or as complex, a mission as desired. Completion of a mission is guaranteed through a "complete plan" including time traps and error recovery procedures. Experimental results are given illustrating the performance attained.

A particular case of the technique developed has resulted in a method to navigate an AUV in a local area (around a mine-like object) using a profiling sonar sensor for position information derived from underwater feature detection. Since sonar image feature extraction is necessarily time consuming, a dynamic model of the vehicle response is used for control between position updates. A structured formulation of this control/navigation method is presented followed by results from in water implementation using the NPS Phoenix vehicle and the tri-level software structure described above.

INVESTIGATION OF THE EFFECT OF TWO-DIMENSIONAL CAVITIES ON BOUNDARY LAYERS IN AN ADVERSE PRESSURE GRADIENT

Richard J. Margason, Civilian, National Aeronautics and Space Administration
B.S., San Jose State University, 1960
M.S., Virginia Polytechnic Institute and State University, 1968
Doctor of Philosophy in Aeronautical Engineering-March 1996
Advisor: Max F. Platzer, Department of Aeronautics and Astronautics

The present investigation evaluated one aspect of the feasibility of the use of multiple cavities as an airfoil high-lift device. The effects of cavities on the boundary layer characteristics in several pressure gradients were determined experimentally and computationally. Experimentally, it was found that up to four cavities could be deployed with only a small change to the boundary layer profiles downstream of the cavities and without significantly modifying the resultant streamwise pressure distribution. From the computational results for both of the wind tunnel test section lengths used in the experimental investigation, it was found that a grid which provided a converged solution in less than

a few hundred iterations was needed before a reasonable comparison with experimental data could be obtained. It was also found for these converged solutions that the appropriate grid clustering and density as well as the cell size required for a satisfactory solution was not always apparent before comparing computational results with experimental data. Overall, the investigation results show that a multiple cavity high-lift concept may be feasible.

NUMERICAL SIMULATION OF THE FLOW FIELD ABOUT A MULTI- ELEMENT AIRFOIL WITH OSCILLATING FLAP

Miguel A. Ortiz-Lieutenant Commander, United States Navy
B.S., Embry-Riddle Aeronautical University, 1982
Master of Science in Aeronautical Engineering-March 1996
Advisor: Max F. Platzer, Department of Aeronautics and Astronautics

Investigation of steady and unsteady flowfields over airfoils is an active area of current computational and experimental research. In this study, the compressible, viscous, flow over a single and multi-element airfoil is numerically simulated by solving the Navier-Stokes equations. The motivation for this work includes interest in studying the effects of a stationary/flapping airfoil combination in tandem configuration. A single-block Navier-Stokes (NS) solver is employed to compute unsteady flowfields. Turbulence is treated using the Baldwin-Lomax turbulence model. A single C-grid is generated and it is partially distorted to simulate the flapping motion. Numerical solutions are obtained for flows at a fixed angle of attack and for unsteady flows over flapping airfoils. The numerical solutions agree well with the experimental data. The difficulties faced during the study are discussed and future improvements are suggested.

OPTIMALITY OF AERO-ASSISTED ORBITAL PLANE CHANGES

Michael S. Parish II-Lieutenant, United States Navy
B. S. M. A., United States Naval Academy, 1988
Master of Science In Astronautical Engineering-December 1995
Advisor: I.M. Ross, Department of Aeronautics and Astronautics

Future spacecraft designs, and in particular military spacecraft, may incorporate the use of synergetic orbital plane change maneuvers. The analysis of these maneuvers and their optimality is an area in which much work has been done but only a few questions have been answered. This thesis discusses the theoretical background for solving the optimal control problem. A framework is set forth for the formulation of the overall problem which must be solved. Pontryagin's Maximum Principle is applied to obtain the necessary conditions for maximizing the inclination change for a given amount of propellant. Effects of a heating rate constraint imposed by the thermal protection system are considered. The Program to Optimize Simulated Trajectories (POST) is used to obtain results for the Maneuverable Reentry Research Vehicle (MRRV) to illustrate certain points. Two characterizations of the atmospheric pass are analyzed and compared to previous work, namely Aerobang and Aerocruise. A discussion on the limited use of POST as a direct method of analysis is also included.

COMPARATIVE COMPUTATIONAL ANALYSIS OF AIRFOIL SECTIONS FOR USE ON SAILING CRAFT

Louis P. Partida-Lieutenant, United States Navy
B.S., United States Naval Academy, 1986
Master of Science in Aeronautical Engineering-March 1996
Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics
Second Reader: Richard M. Howard, Department of Aeronautics and Astronautics

This thesis represents the results of a comparative analysis of current and proposed airfoil sections for use on sailing craft. The primary goal of this report is to develop a sail replacemmnent that functions with the ease and durability of current sailboat sails, yet offers a marked improvement in overall performance, with minimum penalties of weight and

construction complexity. State-of-the-art computational methods are utilized to determine the respective aerodynamic characteristics of a model of a current windsurfer sail section and models of a proposed semi-rigid wing-sail section. Wing-sails offer the same promise of performance gains that modern airfoils have produced in comparison to early thin airfoils. An investigation into differences and possible benefits of the analyzed sections' aerodynamic loading and stall characteristics is made using fully viscous Navier-Stokes Computational Fluid Dynamic codes. Finally a full three-dimensional wing-sail computational model is constructed to identify further areas where sectional improvements would enhance the overall performance of the lifting shape.

BURNING RATES AND ATOMIZATION CHARACTERISTICS OF LIQUID HYDROCARBON FUELS

Kenneth L. Reber-Lieutenant, United States Navy
B.S., University of Colorado, 1989
Master of Science in Aeronautical Engineering-December 1995
Advisor: David W. Netzer, Department of Aeronautics and Astronautics

An investigation was conducted in which the burning characteristics of several liquid hydrocarbon fuels (JP-10, Escorez, Escorez-mixed with JP-10, RJ-7, Mobil E-5, and JP-8) were determined using a windowed combustion bomb at pressures from 1-10 atmospheres. A video camera was used to record the burning of the particles and a frame grabber and a computer were used to extract the data. Fuel atomization characteristics were measured using a standard poppet atomizer and Malvern particle sizer. The burning characteristics of several solvents (Koch 150,150nd,155) with high octane and high flash points were also measured. The burning rates of Escorez/JP-10 mixtures were found to be slightly higher than JP-10 and their volumetric heating values are also higher. Although they were found to have significantly poorer atomization characteristics, the measured particle sizes were small enough to be effectively utilized in ramjet combustors. Pumping characteristics were not measured. Mobil E-5 and RJ-7 were also found to have increased burning rates compared to JP-10. They also have higher volumetric heating values. JP-8 had higher burning rates than JP-10 but has a lower volumetric heating value. The Koch solvents had adequate droplet burning rates, but also significantly increased sooting characteristics.

UNITARY JOINT STANDOFF CAPTIVE AIR TRAINING MISSILE AVIONICS DESIGN THROUGH OPERATIONAL CONCEPTS AND FUNCTIONAL REQUIREMENTS ANALYSIS

Dennis J. Reilly III-Commander, United States Navy
B.S., United States Naval Academy, 1979
Master of Science in Aeronautical Engineering-March 1996
Advisor IsaacI. Kaminer, Department of Aeronautics and Astronautics

To accurately simulate the Unitary Joint Standoff (JSOW) weapon functions and provide pilots with the most realistic training, the captive air training missile (CATM) avionics design will fully implement well defined operational concepts and functional requirements in terms of flight simulation characteristics, operational functions, pilot feedback, and electronic interfaces. This would provide the Navy, Marines, and Air Force with a single, multi-capable, light weight CATM that consolidates CATM procurement, decreases aircraft turnaround time and increases aircrew training per flight hour.

BURNING CHARACTERISTICS OF INDIVIDUAL ALUMINUM/ALUMINUM OXIDE PARTICLES

Eric C. Ruttenberg-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Astronautical Engineering-June 1996
Advisor: David W. Netzer, Department of Aeronautics and Astronautics
Second Reader: Oscar Biblarz, Department of Aeronautics and Astronautics

An experimental investigation was conducted in which the burning characteristics of individual aluminum/aluminum oxide particles were measured using a windowed combustion bomb at atmospheric pressure and under gravity-fall conditions. A scanning electron microscope (SEM) was used to measure the size distribution of the initial aluminum particles and the aluminum oxide residue.

Analysis of the residue indicated that the mass of aluminum oxide contained in particles larger than 12 microns was less than 25 percent, in good agreement with data reported from aluminized solid propellant. The measured particle size distributions and photomicrographs implied that the burning aluminum particles periodically expel aluminum oxide fragments with sizes between 14 and 36 microns.

JSOW CATM CONCEPTUAL WEIGHT AND AIRFRAME DESIGN

Michael T. Scarry-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Aeronautical Engineering-September 1996
Advisor: Gerald H. Lindsey, Department of Aeronautics and Astronautics
Second Reader: Sandra L. Scrivener, Department of Aeronautics and Astronautics

The Joint Stand Off Weapon (JSOW) is a new defense system consisting of a 1065 pound airframe, which includes a 500 pound warhead, to be carried on the F/A-18 Hornet. Training will be accomplished through use of a Captive Air Training Missile (CATM), which is a lighter mock-up of the actual weapon also carried on the wing of the aircraft but not released during training. The JSOW CATM, will need to have very few differences from the actual JSOW Unitary to be an effective training tool. Two main differences are that it will be lighter and have a longer service life. The threshold weight is to be less than 500 pounds, the objective weight is 300 pounds, and the threshold maximum service life is 1500 flight hours, 400 catapult launches and 400 arrested landings. Different CATM variations are considered followed by a strength analysis, using the I-DEAS software, of the most promising variation. This CATM design meets the stated weight objectives. To prepare the CATM for fatigue testing, a proposed service life needs to be defined. The usage of the current IR Maverick CATM over a three year period was examined and used to find the proposed service life of the JSOW CATM. Once the service life was defined, a preliminary fatigue analysis was performed using the I-DEAS software.

INVESTIGATION OF THE EFFECT OF REYNOLDS NUMBER ON LAMINAR SEPARATION BUBBLES ON CONTROLLED-DIFFUSION COMPRESSOR BLADES IN CASCADE

David G. Schnorenberg-Captain, United States Marine Corps
B.S.A.E., University of Minnesota, 1987
Master of Science in Aeronautical Engineering-June 1996
Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics
Second Reader: Raymond P. Shreeve, Department of Aeronautics and Astronautics

Detailed experimental investigation of second-generation, controlled-diffusion, compressor-stator blades at an off-design inlet flow-angle was performed in a low-speed cascade wind tunnel using various experimental procedures. The objective of the study was the characterization of the off-design flow and the detailed investigation of flow separation which occurred near mid-chord. When it was found that the flow separation behavior was strongly influenced by the Reynolds number, the effect of Reynolds number variation on flow separation was investigated. Surface flow visual-

ization was performed to gain general insight into the flow behavior. Blade surface pressure measurements were obtained using instrumented blades, from which coefficients of pressure were calculated. Laser-Doppler velocimetry (LDV) was used to characterize the off-design flow upstream, in the passage between two blades, in the boundary layer on the suction side of the blades, and in the wake region.

Overall, good comparisons between blade surface pressure measurements, LDV data and flow visualization were obtained for the separation region. At the highest Reynolds number, separation was turbulent and three-dimensional and at the low Reynolds number the separation was predominately laminar and two-dimensional.

AN ANALYSIS OF SPACECRAFT DYNAMIC TESTING AT THE VEHICLE LEVEL

Alan Douglas Scott-Commander, United States Navy
B.S., United States Naval Academy, 1981
Aeronautical and Astronautical Engineer-June 1996
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics
Second Reader: Barry S. Leonard, Department of Aeronautics and Astronautics

The U.S. space industry has accumulated a vast amount of expertise in the testing of spacecraft to ensure these vehicles can endure the harsh environments associated with launch and on-orbit operations. Even with this corporate experience, there remains a wide variation in the techniques utilized to test spacecraft during the development and manufacturing process, particularly with regard to spacecraft level dynamics testing. This study investigates the effectiveness of sinusoidal vibration, random vibration, acoustic noise and transient methods of spacecraft dynamic testing. An analysis of test failure and on-orbit performance data for acceptance testing indicates that the acoustic test is the most perceptive workmanship screen at the vehicle level and that additional dynamics tests do not result in an increase in acceptance test effectiveness. For spacecraft qualification, acoustic testing is almost universally employed for qualification in the high frequency environment. For the low frequency environment, data collected from a variety of spacecraft test programs employing sinusoidal sweep, random vibration and transient testing methods shows that a transient base excitation provides the most accurate simulation for the purpose of design verification. Furthermore, data shows that sinusoidal vibration testing provides an unrealistic simulation of the flight environment and results in an increased potential for over testing.

APPLICATION OF PRESSURE-SENSITIVE PAINT IN SHOCK-BOUNDARY LAYER INTERACTION EXPERIMENTS

Douglas L. Seivwright-Lieutenant, United States Navy
B.S., Embry-Riddle Aeronautical University, 1985
Master of Science in Aeronautical Engineering-March 1996
Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics

A new type of pressure transducer, pressure-sensitive paint, was used to obtain pressure distributions associated with shock-boundary layer interaction. Based on the principle of photoluminescence and the process of oxygen quenching, pressure-sensitive paint provides a continuous mapping of a pressure field over a surface of interest. The data measurement and acquisition system developed for use with the photoluminescence sensor was evaluated first using an underexpanded blowing jet over a flat plate. Once satisfactory results were obtained, the system was used to examine shock-boundary layer interaction in a blow-down supersonic wind tunnel at Mach numbers of 1.4 and 1.7. Details of the measurement technique, and discussion of the flow fields which were examined, are reported.

APPLICATION OF NEURAL NETWORKS TO PERISCOPE DISCRIMINATION

Robert N. Severinghaus-Lieutenant, United States Navy
B.S., University of Kansas, 1989
Master of Science in Aeronautical Engineering-March 1996
Advisor: Daniel J. Collins, Department of Aeronautics and Astronautics

The difficulty of detecting a periscope by radar is complicated by false targets. Radar range profiles are used in current correlation techniques to discriminate a periscope from false targets. Neural networks provide an alternative discrimination method that has good generalization and noise rejection features. This study applies neural networks to the periscope discrimination process using commercially available software. Four data input classes were used for training multiple neural networks. The first data input class was the radar range profile. The second data input class was the same as the first, but used a signal-to-noise improvement method to preprocess the radar range profiles. The third data input class used another noise reduction scheme, again on the same data. The discrete Fourier transform (DFT) of the radar range profile produced additional discrimination data. This frequency data was appended to the radar range profile to create a fourth data input class. The results of these neural networks in classification is presented and it is shown that neural networks can discriminate periscopes from false targets with high probability of detection (PD) and low probability of false alarm (PFA).

AN OVERVIEW OF THE PETITE AMATEUR NAVY SATELLITE (PANSAT) PROJECT

Fred J. Severson-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Systems Technology (Space Systems Operations)-December 1995
Advisor: I. Michael Ross, Department of Aeronautics and Astronautics

The main thrust of this thesis is to present a manageable document that accurately portrays the current state of PANSAT and its supporting infrastructure. Research efforts involved investigating a variety of aspects of the PANSAT program including chronology, design, decision processes, and operations. The program objectives include the role of the PANSAT project as an educational tool for officer students and as a proof of concept for a small, digital store-and-forward communications satellite. An extensive list of external agency documentation requirements is also included. Scholastic institutions conducting similar projects could use this thesis as a design guideline as well as to spearhead their documentation efforts. This thesis is meant to be a comprehensive document as well as a suitable starting point for information concerning the PANSAT program.

PROPELLANT FEED CONTROL FOR ION ENGINES

Dan Alexander Starling, Jr.-Lieutenant, United States Navy
B.A., University of Texas at Austin, 1989
Master of Science in Astronautical Engineering-June 1996
Advisor: Oscar Biblarz, Department of Aeronautics and Astronautics
Second Reader: Knox T. Millsaps, Jr., Department of Mechanical Engineering

An overview of space electric propulsion (SEP) is presented. Methods of throttling the power levels of electrostatic and electromagnetic thrusters are discussed. Particular attention is given to the concept of thermally-throttling propellant flow using the temperature-viscosity characteristics of xenon gas. The thermo properties of xenon gas as a function of temperature are determined, and the flow regimes of the propellant at the mass flow rates of interest are studied. The propellant flow is presented separately as Fanno flow and as Rayleigh flow, and then those combined effects are considered. A method for predicting the performance of thermally-throttled systems is presented. Uncertainties in modeling real-world thermal throttling systems are discussed. The possible use of thermal throttling characteristics as a means of propellant pressure regulation is also examined.

EVALUATION OF THE STRAIN ENERGY DENSITY METHOD OF NOTCH STRESS CONCENTRATION CALCULATIONS IN THE PLASTIC RANGE

Grant B. Stephenson-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
M.S., Naval Postgraduate School, 1995
Aeronautical and Astronautical Engineer-March 1996
Advisor: Gerald H. Lindsey, Department of Aeronautics and Astronautics

Accurate stress and strain calculations at a notch usually require a nonlinear finite element analysis when local yielding has occurred. The strain energy density hypothesis is a method to predict these stress and strain values. This method proposes that the plastic strain energy density is equivalent to the strain energy density found assuming the material to be entirely elastic. This hypothesis was evaluated using the finite element method, which was tested by comparing two exact solutions of elastic and elasto-plastic problems, to calculate the stress and strain field for two notched plates of varying widths under elasto-plastic loading. For both geometrics, a plane stress and plane strain analysis was performed.

The elasto-plastic strain energy density from the finite element method was found to be greater than that predicted by this proposal, which in turn resulted in under-predicting the local stresses and strains. This difference was greater for the plane stress condition than for the plane strain condition. Comparisons were also made with notch stresses based on the Neuber method. The two methods appear to give an upper and lower bound to the actual stresses and strains. By combining the results of the strain energy density method and the Neuber method, reasonably accurate estimates of stress and strain values can be obtained.

FLOW VISUALIZATION AND OPTIMIZATION OF SIDE-INLET-DUMP LIQUID-FUEL RAMJET COMBUSTORS

Mark L. Stevens-Lieutenant, United States Navy
B.S., University of Kansas, 1987
Master of Science in Astronautical Engineering-December 1994
Advisor: David W. Netzer, Department of Aeronautics and Astronautics

Four variations of a single side inlet-dump ramjet combustor were examined using laser Doppler velocimetry and laser sheet flow visualization in a water tunnel. The baseline configuration was an inlet that dumped into the combustor at an angle of twenty degrees with respect to the combustor axis. The different inlet variations that were tested included an inlet aerogrid and two different scallop arrangements. The baseline combustor produced two large recirculation regions and large-scale structures shed from the dump plane. Very little fine-scale mixing was present. The flowfield would be conducive to combustion instability and low combustion efficiency. The aerogrid reduced the size of the recirculation regions, eliminated the large-scale vortices shed from the inlet dump and increased fine-scale mixing. These flow conditions would be conducive to high combustion efficiency and to minimum combustion instability, but may result in narrower flammability limits. Two different scalloped inlet arrangements were tested with the goal of providing the benefits of the aerogrid but with wider flammability limits and less pressure drop across the inlet. A geometry producing high-amplitude, low-frequency flow structure showed promise but further optimization is required.

LIQUID HYDROCARBON FUEL COMPOSITION EFFECTS ON PLUME CHARACTERISTICS

Andrew W. Swenson-Lieutenant, United States Navy
B.S., Purdue University, 1986
Master of Science in Astronautical Engineering-December 1995
Advisor: David W. Netzer, Department of Aeronautics and Astronautics

An experimental investigation was conducted to measure the effect of commercially available fuel additives and mixture ratio on the sooting properties and the IR signature of a kerosene-oxygen rocket plume. Multiple wavelength light extinction measurements were made together with measurements of the plume mid-IR signature. A Mie code was used

to obtain the mean extinction coefficients as a function of the particle size distribution, complex index of refraction, and wavelengths of the collimated illuminating source. This initial investigation showed that the use of 0.6% by volume of Wynn's Emission Control Plus fuel additive in kerosene significantly reduced the plume soot concentration and radiance in the 3.5-5.0 μm IR band of a kerosene-oxygen rocket engine operating with an equivalence ratio of approximately 2.0. The size distribution and optical properties of the soot were not significantly altered. These initial results indicate that the mid-IR plume signature of kerosene burning rocket engines may be significantly altered using inexpensive, commercially available fuel additives. Further testing is required to examine wider ranges of engine operating conditions.

RECOVERY FACTORS IN ZERO-MEAN INTERNAL OSCILLATORY FLOWS

Nicole Lynn Tait-Lieutenant, United States Naval Reserve
B.S., University of Maryland, 1989
Master of Science in Mechanical Engineering-December 1995
Master of Science in Astronautical Engineering-December 1995
Advisors: Ashok Gopinath, Department of Mechanical Engineering
Oscar Biblarz, Department of Aeronautics and Astronautics

High speed oscillatory flows, like high speed mean flows, are capable of inducing time-averaged heat transfer effects. This research involves the analytical solution of a model problem of zero-mean internal oscillatory flow, which arises from a high-intensity resonant standing acoustic wave set up across the ends of two parallel plates. The compressible form of the Navier-Stokes equations are solved, along with the equations of continuity, energy, and state, using perturbation solution and complex variable methods. MAPLE, a symbolic mathematical software tool, is utilized to find the time-averaged portion of the temperature distribution between the plates. The final heat transfer results are presented in terms of suitably defined recovery factors. The analysis is performed for varying gap widths between the plates using air as the host fluid. This work provides the fundamental explanation of the phenomenon responsible for the thermoacoustic refrigerating effect as well as an analytical basis for determining the optimum gap width between the plates of the stack in a thermoacoustic refrigerator.

MOTION PLANNING AND DYNAMIC CONTROL OF THE NOMAD 200 MOBILE ROBOT IN A LABORATORY ENVIRONMENT

Ko-Cheng Tan-Lieutenant Commander, Republic of China Navy
B.S., Chinese Naval Academy, 1984
Master of Science in Aeronautical Engineering-June 1996
Advisor: Xiaoping Yun, Department of Electrical and Computer Engineering
Second Reader: Isaac Kaminer, Department of Aeronautics and Astronautics

Motion planning and control of a Nomad 200 mobile robot are studied in this thesis. The objective is to develop a motion planning and control algorithm that is able to move the robot from an initial configuration (position and orientation) to a goal configuration in a typical laboratory environment. The robot must be able to avoid unknown static (e.g., walls and tables) and dynamic (e.g., people) obstacles. Dubin's algorithm finds the shortest path connecting two configurations in an obstacle-free environment, but it is not able to avoid obstacles present in the environment. The potential field algorithm is effective in avoiding unknown obstacles, but it has the local minimum problem and does not consider the orientation of a mobile robot. A modified potential field algorithm is first developed. The algorithm overcomes local minima in a typical laboratory environment. The modified potential field algorithm is then combined with Dubin's algorithm to incorporate orientation into motion planning. The combined algorithm is able to avoid static and dynamic obstacles and achieve position and orientation requirements. Simulation and physical experiment results are presented to demonstrate the effectiveness of the algorithm.

PERFORMANCE AND OPTIMAL PLACEMENT OF PIEZOCERAMIC ACTUATORS FOR SHAPE CONTROL OF A CANTILEVER BEAM

Kirk E. Treanor-Lieutenant, United States Navy
B.S., University of California Los Angeles, 1987
Aeronautical and Astronautical Engineer-June 1996
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics
Second Reader: John L. Meyer, Department of Aeronautics and Astronautics

Shape control of spaceborne antennas can provide the ability to correct for effects such as thermal distortion and manufacturing errors as well as control the shape of an antenna's radiated beam. This thesis examines the performance of piezoceramic actuators in producing static deformation of a cantilever beam and analyzes the optimal placement of actuators to best approximate a desired deformation profile. Predictions of actuator effectiveness at producing curvature are developed using an Euler-Bernoulli model. An algorithm to determine the optimal locations and input voltages for a fixed set of actuators to achieve a desired deformation profile of a cantilever beam using embedded Nelder and Mead simplex search routines is presented and evaluated for two shape functions and various combinations of actuators. Experimental measurements show that the Euler-Bernoulli model provides a reasonable prediction of actuator performance at low input voltage but does not account for nonlinear behavior of the piezoeceramic and the effects of hysteresis and transverse stresses. Further experiments demonstrate the ability of four piezoceramic actuators to produce an approximation of a parabolic deformation profile of a cantilever beam and illustrate the importance of considering these effects in determining the required actuator input voltages.

PARTICULATE SIZING IN GAS TURBINE EXHAUST USING A LASER EXTINCTION TECHNIQUE

Philip H. Turner-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Master of Science in Astronautical Engineering-December 1995
Advisors: Oscar Biblarz, Department of Aeronautics and Astronautics
David Netzer, Department of Aeronautics and Astronautics

The measurement of soot particulates densities in gas turbine engine and rocket exhausts is an area of continuing scientific investigation. Knowledge of exhaust plume soot concentration and sizing is critical for plume signature determination, currently a focus of theater ballistic missile defense research. This thesis research investigates the development and initial calibration of an instrument that will determine soot particle densities in an exhaust plume, by measuring the absorption of a light beam transmitted through the plume. This instrument utilizes an argon ion laser, four passes through the exhaust plume, and a phase conjugate crystal to correct for aberrations in the transmitted beam. Several aspects of instrument layout and performance were investigated, and an initial calibration against a conventional probe sampling technique was performed, using an ethelyne-air combustor as a soot source. While soot concentration measurements obtained with the instrument were internally consistent, the primitive sample probe used limited the opportunity to do an accurate comparison against a conventional method. The method requires further development, but shows significant promise for use in a jet engine test cell.

UNITARY JOINT STANDOFF WEAPON CAPTIVE AIR TRAINING MISSILE FLIGHT SIMULATION

David R. Wagner-Commander, United States Navy
B.S., United States Naval Academy, 1981
Master of Science in Aeronautical Engineering-September 1996
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics

During the past year, a student/faculty team at the Naval Postgraduate School Aeronautics and Astronautics Department has been engaged in developing functional requirements for the Unitary Joint Standoff Weapon (JSOW) Captive

Air Training Missile (CATM). One such requirement calls for pilot steering commands to be synthesized and displayed in the cockpit during JSOW training missions. A comprehensive understanding of the JSOW's guidance and control system's performance in free flight is critical to obtaining truly pilot-friendly steering commands and displays. To this end, this thesis models the JSOW guidance and control system using Matlab/Simulink software and offers the necessary framework for developing pilot-steering commands and displays.

VULNERABILITY OF INTELSAT/VSAT SYSTEMS

Kevin M. Wilson-Lieutenant Commander, United States Navy
B.S., University of Houston, 1985
Master of Science in Astronautical Engineering-June 1996
Advisor: Vicente Garcia, Department of Electrical and Computer Engineering
Second Reader: Sandra Scrivener, Department of Aeronautics and Astronautics

This thesis considers the Navy's use of the International Telecommunications Satellite (INTELSAT) system with emphasis on the future utilization of Ku-band Super High Frequency (SHF) communications in the Navy's satellite communications architecture. In particular, it evaluates the use of very small aperture terminal (VSAT) networks in conjunction with the INTELSAT system. The scenario examined will be an hypothetical contingency operation with the U.S. Navy supporting a joint special operations force (JSOF) in a coastal region by providing communications, command, control and intelligence support using an INTELSAT/VSAT system.

The increased and mandated use of commercial satellite technology leads to a whole new arena of potential risks to exploitation. Critical vulnerability issues such as detection and interception, and anti-jamming will be addressed. This thesis is designed to aid the communications planner in his/her efforts to support the satellite communications requirements of the military end-user.

INTEGRAL HYBRID-BOOST/SOLID-FUEL RAMJET PROPULSION FOR LIGHTWEIGHT TACTICAL MISSILES

Paul C. Woods-Lieutenant, United States Navy
B.S., University of Washington, 1987
Aeronautical and Astronautical Engineer-December 1995
Advisor: D. W. Netzer, Department of Aeronautics and Astronautics

An investigation was conducted to determine the feasibility of a small, low-cost, caseless, hybrid-booster/solid-fuel ramjet (H/SFRJ) that utilizes a common fuel grain and has no ejectables. Performance of an air-to-ground missile with a solid propellant booster and SFRJ sustainer, capable of being fired from an unmanned aerial vehicle or helicopter was obtained using an Air Force computer code. A H/SFRJ motor was then designed analytically and compared to the generated computer output. The results showed that a H/SFRJ that has performance equal to a solid-booster SFRJ is feasible. The final missile design had a range of 20 nm, a flight Mach number of 2.0, a diameter and length of 5 and 99 inches respectively, and weighed 82 lb. Caseless hybrid rockets with erodible nozzles were tested to validate assumptions made in the design analysis. In addition, transition from hybrid-rocket booster to solid-fuel ramjet sustainer was demonstrated.

EXPERIMENTAL INVESTIGATION OF FLOW CONTROL BY MEANS OF AIRFOIL FLAPPING

Jiannwoei Yue-Lieutenant Colonel, Republic of China Army
B.S., Chung-Cheng Institute of Technology, 1978
M.S., Chung-Cheng Institute of Technology, 1984
Master of Science in Mechanical Engineering-September 1996
Advisors: Max F. Platzer, Department of Aeronautics and Astronautics
J.D.S. Lai, Department of Aeronautics and Astronautics
M.D. Kelleher, Department of Mechanical Engineering

Flapping airfoils generate thrust-producing jet-like wakes. It therefore is the objective of this investigation to explore whether this feature can be used for effective flow control. To this end, the flow characteristics of flapping airfoils are first explored in a water tunnel experiment, using dye flow visualization and laser-Doppler velocimeter. The effect of airfoil flapping frequency and amplitude of oscillation and of flow velocity on the wake flow characteristics are determined. This is followed by a second water tunnel experiment, where a small flapping airfoil is mounted in and near the separated flow region caused by the flow over a backward-facing step. The effect of airfoil size, location, frequency, and amplitude of oscillation on the separated flow region is again determined by means of laser-Doppler velocimeter. It is found that the reattachment length of the separated flow region can be reduced by as much as 70%.

UNIFORM SYSTEM FOR THE RAPID PROTOTYPING AND TESTING OF CONTROLLERS FOR UNMANNED AERIAL VEHICLES

James A. Zanino-Lieutenant, United States Navy
B.S., Boston University, 1988
Master of Science in Aeronautical Engineering-September 1996
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics
Second Reader: Richard M. Howard, Department of Aeronautics and Astronautics

The field of control systems has witnessed an explosion in state-space techniques addressing a variety of critical design issues facing control engineers today. Modern computational tools, such as the Matrix$_x$ Product Family developed by Integrated Systems Incorporated, allow the designer to quickly design, test and implement control systems based on these state-spaced techniques. These new computing advances shorten the time required to complete a control design from a few years to a few months. However, as the design process progressed new inputs and outputs were required, which usually resulted in a confusing mess of connections that were hard to follow. Therefore, a universal system was needed that could be used on any controller design to aid in the understanding and tracking of the controller's inputs and outputs. A description of this system is given along with a detailed step by step process on how it was implemented on a Unmanned Air Vehicle (UAV).

THE APPLICATION OF VIDEOGRAMMETRY IN THE STRUCTURAL TESTING OF SPACECRAFT

Kevin D. Ziomek-Lieutenant, United States Navy
B.S., Villanova University, 1990
Master of Science in Astronautical Engineering-June 1996
Advisor: Sandra L. Scrivener, Department of Aeronautics and Astronautics
Second Reader: Joshua Gordis, Department of Mechanical Engineering

This thesis will study the application of video photogrammetry in satellites and space systems. Industrial photogrammetry provides an extremely accurate and versatile means for non-contact, three-dimensional digitizing of a sample of points on an object of interest. Photogrammetry is non-invasive, because it measures photographic negatives of the object, not the object itself. Its flexibility and versatility are derived from photogrammetry's ability to view the object from many different angles in almost any test configuration. Using the process of optical triangulation the two-dimen-

sional images from the different views are transformed into three-dimensional coordinate data. This data is then analyzed to provide the desired results. Tests were conducted during an experience tour at TRW Space and Electronics Division, Redondo Beach, California. The applications include a K-Biaxal unit rotation and orthogonality test, a boom stiffness test. The analysis will address the accuracy, versatility and adaptability, speed, and reliability of videogrammetry and compare it to other current test procedures such as linear variable differential transformers (LVDT) and strain gages.

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